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EXPERIMENTAL AND THEORETICAL STUDY FOR DEVELOPMENT OF AN IMPROVED REINFORCED FLEXIBLE WINDOW

BY

DON E. HILE, JR.

Prepared under Contract No. NAS1-7771 by

UNIROYAL, INCORPORATED

Mishawaka, Indiana

for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Applied Materials and Physics Division
Spacecraft Systems Branch
Langley Research Center
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ADMINISTRATIVE INFORMATION

This report was prepared by the Engineered Systems Department of UNIROYAL, Inc., Mishawaka, Indiana, under National Aeronautics and Space Administration Contract NAS1-7771.

The contract for Experimental and Theoretical Study for Development of an Improved Reinforced Flexible Window was administered under the direction of Mr. Jerry G. Williams of the Applied Materials and Physics Division, Spacecraft Systems, National Aeronautics and Space Administration, Langley Research Center, Langley Station, Hampton, Virginia.

The final report covers the period 19 December 1967 to 11 July 1969.

This report was compiled and prepared by Mr. D. E. Hile, Jr., under the direction and approval of Mr. R. C. Kohrn, Manager Engineered Systems Department, with Mr. D. D. M. Streed serving as Product Manager, and Mr. G. E. Kelsheimer as Chief Consultant. Considerable assistance was given by Mr. L. D. Searer, Mr. D. Catanzarite, Mr. C. L. Egbert, and Mr. E. E. Jordan.

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SUMMARY

The objective of this program was to develop an improved flexible transparent space window suitable for use in a flexible expandable space structure.

During the course of this contract, a window composite was developed which exhibits superior properties in comparison to earlier constructions. The window construction consists of silicone encapsulated polyether urethane matrix reinforced with a carbon steel rocket cable pattern. The composite exhibits excellent flexibility with an overall thickness of 2.54 mm; pressure resistance to 24.30 nscm, heat resistance, (150° C for 24 hours), and excellent optical transparency.

INTRODUCTION

Advanced manned space programs indicate a requirement for visual observation of experiments and subsystems located exterior to the space structure. Indicative of this need was NASA Contract NASI 5524, "Feasibility Study for Development of a Flexible Reinforced Window". This earlier contract established many of the parameters for a flexible space window capable of withstanding the rigors of the outer space environment. The window construction developed consisted of a glass filament reinforced dimethyl silicone polymer with an overall thickness of 4.825 mm.

It was the expressed purpose of the present contract to advance the state-of-the-art in materials and fabrication methods for the flexible space window.

TECHNICAL GUIDELINES

The following technical guidelines were established in order to assist in formulating design parameters:

1. The material is assumed to be exposed to the space environment including; hard vacuum, temperature extremes micrometeoroids, and radiation (ultraviolet and particulate).
2. Materials are assumed to be exposed to mechanical damage such as scratching by a sharp instrument.
3. The window structure shall be as flexible as practical.
4. The ultimate strength goal for the window shall be 1261 n/cm in the direction of maximum stress.
5. The blowout strength of the window shall be based upon a 4.86 nscm pressure differential with a safety factor of five.
6. The window shall be designed to exhibit good optical transparency under a pressure differential of 4.86 nscm.
7. The window shall be adhesively attached to the flexible wall structure.
8. The overall design thickness required of the window composite is 2.286 mm.

LIST OF SYMBOLS AND CONVERSIONS
USED IN TEXT

1.	nscm	Newtons per square centimeter internal pressure
2.	n/cm	Newtons per linear centimeter
3.	mm	Millimeters
4.	kg/m^2	Kilograms per square meter at given thickness
5.	H.T.S.	High Tensile Strength
6.	R.T.V.	Room temperature vulcanizing
7.	mu.	Wavelength in millimicrons
8.	RMS	root mean square
9.	nts	Newton tensile strength

CONVERSION TABLE

1.	1 nscm	= 1.440329 pounds per square inch
2.	1 n/cm	= .566684 pounds per inch
3.	1 mm	= .03937 inches
4.	1 kg/m^2	= .001422 pounds (Mass) per square inch at a given thickness

PHASE I

MATERIALS SELECTION AND EVALUATION

Transparent Polymer Study

Major emphasis in this phase was placed on the selection of a transparent matrix polymer possessing the processing characteristics necessary in the fabricating of a low-gauge reinforced composite and having the desired optical and environmental resistant properties. In the study three generic types of polymers were evaluated:

A) Polyurethanes

B) Dimetyl silicones

C) Polyvinyl butyrals.

Table I lists those polymers receiving initial consideration. From these materials numerous formulations were made in order to improve processability and/or physical properties of the resultant films. Various solvent systems were used in attempts to improve flow characteristics for processing. Flame retardants and ultraviolet absorbers were additives evaluated to improve the heat and light stabilities of the urethane compounds.
On the basis of conclusions from the previous related contract - NASI 5524 - that it was not feasible to incorporate a reinforcement grid pattern in a molded window panel without severe air entrapment, only castable compounds were considered.

TABLE I

OPTICALLY TRANSPARENT POLYMERS

Code Number	Polymer	Source
	Urethane	
U-1	Estane 5740 x 140 (polyester)	B. F. Goodrich
	Vibrathane	Uniroyal-Chem. Div.
U-2	V 6007/V6004 (polyester)	
U-3	V 6004 "	
U-4	V 6001 "	
U-5	V-B-600 (polyether)	
U-6	Roylar E-9 (polyester)	Uniroyal-Chem. Div.
U-7	Conathane EN 1554 (polyether)	Conap, Inc.
U-8	Conathane EN 1500 "	" "
U-9	Castomer A-4 (polycaprolactone prepolymer)	Isocyanate Products, Inc.
U-10	Spencer Kellogg XP-1926 (aliphatic)	Spencer Kellogg
	Silicone	
S-1	Dimethyl R.T.V. #615	General Electric
S-2	Dimethyl R.T.V. Sylgard 184	Dow Corning
S-3	" " " 186	" "
S-4	" " 93079	" "
	Polyvinyl Butyral	
P-1	Butvar B 90	Monsanto
P-2	Butysite 10 (film stock)	Du Pont
P-3	Mowital B 60H	Hoechst A.G. (Germany)

Major consideration was given to the urethane candidates because of their strength, flexibility, and bonding characteristics in contrast to the silicones with their inherent adhesion inadequacies[1] and the butyrals which by nature are moldable polymers.

In the preliminary screening of the candidate compounds, 1651 square centimeter films were cast. A variety of formulations were considered with each compound in an attempt to eliminate or compensate for any recognizable deficiencies. Each film was then visually inspected. Table 2 indicates those areas in which a majority of compounds were found to be inadequate for the window matrix application.

[1] The most troublesome area in the fabrication of the window composites of the previous contract (NASI-5524) was in obtaining a reliable bond between the supporting material and the silicone matrix in order to seal the window attachment area.

TABLE 2

CRITERIA FOR REDUCTION OF CANDIDATE COMPOUNDS

Characteristic for which Compounds were Eliminated	Compound Code (See Table 1) u 1	u 2	u 3	u 4	u 5	u 6	u 7	u 8	u 9	u 10	s 1	s 2	s 3	s 4	p 1	p 2	p 3
Transparency				x		x							x	x		x	
Processibility		x	x		x	x				x				x	x	x	x
Flexibility																x	x
Surface Irregularity		x			x			x							x	x	x
Distortion		x						x	x								
Tensile Modulus											x						
Surface Hardness														x			
Air Entrapment			x						x								
High Viscosity			x	x	x				x					x			
Notch Sensitivity											x	x					

Estane 5470 x 140 (compound U-1) and Conathane EN 1554 (Compound U-7) displayed the greatest potential among the numerous compounds for a reinforcement encapsulating matrix. Silicone Compound S-2 (Sylgard 184), although not possessing the desireable characteristics for a matrix film, did exhibit excellent processibility, transparency, and light stability and was, therefore, considered for further evaluation as a potential low thickness exterior lamina film. Tables 17, 18, and 19 in Appendix B show comparative values for compounds U-1, U-7 and S-2. It is significant that Compound U-7 exhibited a substantial reduction in transparency after exposure to ultraviolet light for 240 hours (Table 20). This condition is an indication of the breakdown of molecular bonds which results in a rapid surface oxidation particularly damaging in the low range of the ultraviolet spectrum. With the existance of this condition the potential of a laminate construction with the urethane encapsulated by a shielding material was greatly enhanced.

Along with silicone (Sylgard 184) which had already been introduced as an exterior "barrier" lamina, NASA and Uniroyal were interested in several transparent film stocks with superior ultraviolet, high temperature, and flame resistant properties. Table 3 lists those films considered for potential use as "barrier" laminae.

TABLE 3

Candidate Barrier Films

No.		Type	Supplier
1	Teflon C-20	flourinated ethylene propylene	Du Pont
2	Aclar 22A	fluorohalocarbon	Allied Chemical
3	Kel-F 81Kx8205	chloro-trifluoroethylene	3 M
4	Tedlar 50AM20TR	polyvinyl fluoride	Du Pont
5	Bakelite C-4	-	Union Carbide
6	Dexil *	polycarboranesiloxanes	Olin Chemical
7	Kapton 100 H	polyimide	Du Pont
8	(Experimental)	fluorosulfonic acid membrane	Du Pont
9	Lexan	polycarbonate	General Electric
10	Kodacel TA 401	cellulose triacetate	Eastman Chemical
11	Cronar (mylar)	polyethylene terepthalate	Du Pont
12	Saran	polyvinylidene chloride copolymer	Du Pont

* This film was not evaluated due to limited availability. All other films were purchased and evaluated.

The actual consideration of barrier film candidates was initiated in the early stages of Phase I and continued on into Phase II. Only films 4, 9, 10, 11, and 12 (See Table 3) were obtained and evaluated prior to the fabricating of the nonreinforced laminate composite panels of Phase I. Films 9 and 10 "Lexan", and "Kodacel" respectively were the only candidates at this early stage with potential application. Because of the similarity in physical properties of these two films only the "Lexan" was incorporated into the nonreinforced laminate construction evaluation. To include both films was considered to be a duplication of effort. Both films 9 and 10 were later to be discontinued as a result of the overall rigidity that each film contributed to the laminate construction.

At the conclusion of Phase I consideration was still being given to films No. 1, 2, 3, and 7. Table 21 presents a comparison of "the elongation vs. tensile strength" for the four prime barrier film candidates. In subsequent adhesion trials, Urethane 7 was cast onto the films, and the laminates were in turn evaluated for transparency and flexibility as well as bond strength. Although the transparencies and bond strengths were found to be adequate, a phenomena became apparent in all four systems upon flexing which was totally unacceptable in a flexible system. This condition was a rippling in the barrier film which was the result of the film being strained (when flexed and returned) beyond its elastic limit. The films did not possess an elasticity compatible with the urethane film and for this reason were not considered in Phase II composites.

Table 4 in a similar manner as Table 2 indicates the particular characteristic of each film which eliminated it from further consideration in the window composite. It should be noted that the physical characteristics are listed in the order in which they became apparent during the course of the evaluation program.

TABLE 4

CRITERIA FOR DISPOSITION OF BARRIER FILM CANDIDATES

No.	Barrier Film	CHARACTERISTICS Availability	Transparency	Bondability	Flex. in Laminate	Elasticity
1	Teflon					X
2	Aclar					X
3	Kel-F			X		X
4	Tedlar		X			
5	Bakelite C-4				X	
6	Dexil	X				
7	Kapton					X
8	Fluorosulfonic Acid Membrane	(limited) X				
9	Lexan				X	
10	Kodacel				X	
11	Cronar		(milky) X		X	
12	Saran			X		

NONREINFORCED LAMINATE CONSTRUCTIONS

Table 5 lists the ten nonreinforced laminate constructions fabricated, evaluated, and submitted to the NASA Project Engineer.

Table 5

NONREINFORCED LAMINATE CONSTRUCTIONS

Panel Number	Laminates		Total Thickness
1	Estane 5740 x 140	control panel	2.24 mm
2	Conathane EN 1554	" "	2.71 mm
3	Sylgard 184 - silicone	" "	2.42 mm
4	Sylgard 184 - 0.76 mm/Estane - 1.42 mm		2.18 mm
5	Conathane - 1.27 mm/Conathane - 1.17 mm		2.44 mm
6	Conathane - 0.76 mm/Sylgard 184 - 1.52 mm		2.28 mm
7	Conathane - 1.14 mm/Sylgard 184 - 1.52 mm		2.66 mm
8	Polycarbonate - 0.38 mm/Conathane - 1.87 mm		2.25 mm
9	Polycarbonate - 0.38 mm/Conathane - 0.94 mm/Conathane - 1.52 mm*		2.84 mm
10	Polycarbonate - 0.38 mm/Sylgard 184 - 1.77 mm		2.15 mm

* This laminate contained Brominex 126 (bromine containing polyol) a flame retardant - Swift & Co.

Table 6 compares the visual transparency of the ten laminate panels after 3 different exposures - unaged, aged 1 week at 100° C., and aged 240 hours - ultraviolet.

Table 6

NONREINFORCED LAMINATE PANELS - VISUAL QUALITY

(See Table 5 for Panel Construction)

Panel No.	Unaged*	Aged 1 Week-100° C	Aged 240 Hrs.-Ultraviolet**	Surface Exposed
1	Clear (light amber)	Clear (amber)	Opaque, clarity impaired	-
2	Clear (light amber)	Clear (amber)	Transparency lost	-
3	Clear	Clear	Clear	-
4	Clear (light amber)	Clear (light amber)	Opaque, clarity impaired	U-1
5	Clear (light amber)	Clear (amber)	Crazed, clarity impaired	-
6	Clear (light amber)	Clear (amber)	Crazed, clarity impaired	U-7
7	Clear (light amber)	Clear (amber)	Clear (amber)	S-2
8	Clear (light amber)	Clear (amber)	Clear (dark amber)	U-7
9	Clear (dark amber)	Clear (very dark amber)	Transparency lost	U-7
10	Clear	Clear	Clear	S-2

* All panels had good optical transparency in the unaged state.
** See Appendix A, page 58 for description of ultraviolet exposure.

The most significant finding in the visual quality test was the difference in clarity of #6 and #7 after 240 hours of ultraviolet exposure. Both panels had the same construction - Conathane EN 1554/Sylgard 184, however, #7 maintained visual transparency while #6 was crazed and had an impairment in its transparency. The explanation lies in the surface that was exposed to the ultraviolet light. Panel 7 had the ultraviolet-stable silicone exposed directly while Panel 4 and 6 had the urethane film exposed directly to the ultraviolet light.

In Table 22,Appendix B, the percent light transmittance is compiled for all ten laminate panels before and after exposure to the two aging conditions. As revealed in the Table, Panel 7 exhibited a greater transmittance of light at all points along the spectrum than did either panel 4 or 6.

As a result of the nonreinforced laminate panel evaluations, it was concluded that Urethanes #1 and #7 have the greatest potential of all the materials considered for a reinforcement encapsulating matrix film. It was also concluded that Silicone #2 with its excellent ultraviolet stability could play a significant role in the window composite as an external lamina.

REINFORCEMENT SYSTEM

In the previous NASA Space Window Contract - NASI-5524 - three types of reinforcing materials were evaluated - fiberglass, steel, and polyester. Conclusions from this contract indicated a preference for the fiberglass but noted that methods of preimpregnating the glass prior to winding the reinforcement pattern should be investigated in order to eliminate problems encountered in the winding operation and to improve the adhesion to the matrix material. The latter problem of adhesion was not relevant because of the new generic matrix material which evolved from earlier development efforts of this contract.

With this background, two fiberglass rovings and two steel wire candidates were selected for preliminary consideration.

Reinforcement Candidates:

GL-1 - 901-S - HTS finish - G* filament size - Owens Corning Fiberglass Corp.

* One end of glass roving in this report consists of 204 G size filaments. A "G" size filament has a diameter of 9.62×10^{-3} mm.

GL-2 - 1014-S G filament size glass roving - Ferro Corp.

ST.-1 - 0.1016 mm brass plated carbon rocket wire 399,478 nscm Minimum Tensile-National Standard Corp.

ST.-2 - 0.3175 mm brass plated carbon rocket wire cord* 399,478 nscm, Minimum Tensile-National Standard Corp.

ST.-2 was chosen as the steel reinforcement candidate for the following reasons:

1. Simplification of fabrication
2. Reduced likelihood of strand damage during fabrication.
3. Better flexibility in cable than in comparable number of individual strands.
4. More uniform tension.
5. More uniform pattern contributing to superior optical transparency.

During the course of NASA Contract NASI-5524, numerous glass filament reinforced composites were fabricated. Throughout this earlier contract the following problems were encountered: 1) maintaining uniform tension on all the ends twisted into individual cords, 2) preventing the breakage of the glass filaments during the winding of the reinforcement patterns, 3) adequately wetting the glass roving in order to minimize friction and to facilitate a uniform load transfer among the individual filaments. As a result of these findings in the previous contract, it was recommended that in this contract (NASI-7771) a study be conducted regarding the feasibility of preimpregnating the twisted glass roving prior to the winding of the reinforcement pattern.

* ST.-2 consists of seven strands of ST.-1 wound in a cable yielding an efficiency of 95% for the equivalent number of individual ST.-1 strands. Since the two glass filament candidates had virtually identical properties, GL-1 was selected on the basis of ready availability from the suplier in a single end roving.

In Phase I GL-1 glass roving was given a predetermined number of twists and then drawn through a solution (25% solids) of Estane 5740 x 140 (U-1). It was necessary to wipe the coated glass as it passed from the bath in order to prevent an excessive build-up of resin on the glass. The wiping operation, however, caused the roving to flatten-out in areas which resulted in a nonuniform roving diameter not conducive to a low thickness, uniformly spaced netting pattern.

The glass reinforced panels constructed in Phase I which utilized the pre-impregnated roving (Figures 1 and 2) did not possess those optical properties considered essential in the window composite. With the coated roving's nonuniform diameter, it was not possible to wind a symmetrical netting pattern with uniform reinforcement placement.

In addition to the above finding, with the selection of a urethane matrix, the problems previously encountered in regard to adhering the glass roving to the matrix were virtually eliminated.[2]

DESIGN OF REINFORCEMENT PATTERN

The physical strength requirements for the flexible window system were established in the Technical Guidelines of the Work Statement:

Circumferential Strength - 128.4 kg/cm.

Axial Strength - 64.2 kg/cm.

The reinforcement patterns were selected based on judicious placement of the calculated reinforcement material requirement establisehd using the design tensile strength parameters for the respective reinforcement materials:

[2] In the previous Contract-NASI 5524 with the selection of RTV silicone as the window matrix candidate, problems were encountered in adhering the matrix to the reinforcement materials.

1. GL-1 one end HTS 901-S glass roving - 26.69 nts.

2. ST.-2 - one end brass plated carbon rocket cable - 209.09 nts.

Table 7 indicates the netting pattern design parameters based upon the respective tensile strengths of the two reinforcement candidated.

Table 7

NETTING PATTERN DESIGN PARAMETERS

Code	Reinforcement Material	Reinforcement Direction	No. of Ends/cm	No. of Ends/inch
GL-1	HTS-901-S glass roving	Circumferential	50.40	128
GL-1	" " " "	Axial (longitudinal)	25.20	64
ST.-2	7 Strand carbon rocket wire	Circumferential	6.30	16
ST.-2	7 " " " "	Axial (longitudinal)	3.15	8

REINFORCED LAMINATES

Based upon the information obtained from the nonreinforced laminate panels combined with the selection of the two reinforcement materials, five preliminary reinforced window test specimens were designed, fabricated, and tested as outlined in Table 8.

Table 8

REINFORCED TRANSPARENT WINDOW CONSTRUCTIONS

Details	Composite #1	Composite #2	Composite #3	Composite #4	Composite #5
Polymeric Composition	U-7	S-2/U-7/S-2	S-2/U-7/S-2	U-7	U-7
Thickness	3.9370 mm	4.4450 mm	3.8862 mm	3.6830 mm	3.9878 mm
Lamina Thicknesses*		0.508 mm/3.429 mm/ 0.508 mm	0.508 mm/2.8702 mm/ 0.508 mm		
Reinforcement Material	Glass #1	Glass #1	Steel #2	Steel #2	Steel #2
Circumferential	8-16**	8-16	8-2	8-2	4-4
Axial	8-8	8-8	8-1	8-1	4-2
Reinforcement Pattern Dimension	6.35 mm x 6.35 mm	3.175 mm x 3.175 mm	3.175 mm x 3.175 mm	3.175 mm x 3.175 mm	6.35 mm x 6.35 mm
Test Results					
Deflection***	10.668 mm	11.811 mm	12.6492 mm	10.642 mm	9.956 mm
Optical Quality	Pattern Distortion	Slight Distortion - Readable	Slight Distortion - Readable	Blurred - Not Readable	Blurred, Not Readable

* The lamina thicknesses are calculated on the basis of laboratory samples inasmuch as the above composites were submitted to NASA.

** Interpreted as eight 16 end strands of S glass roving per inch.

*** Maximum deflection of composite pressurized to 4.86 NSCM in a 25.4 cm. diameter pressure fixture - Ref. NASA - C. R. 66299 - "Feasibility Study for Development of a Flexible Reinforced Window", Fig. 2 and Fig. 3

Figure 1

PHASE I - REINFORCEMENT PATTERN - COMPOSITE #1

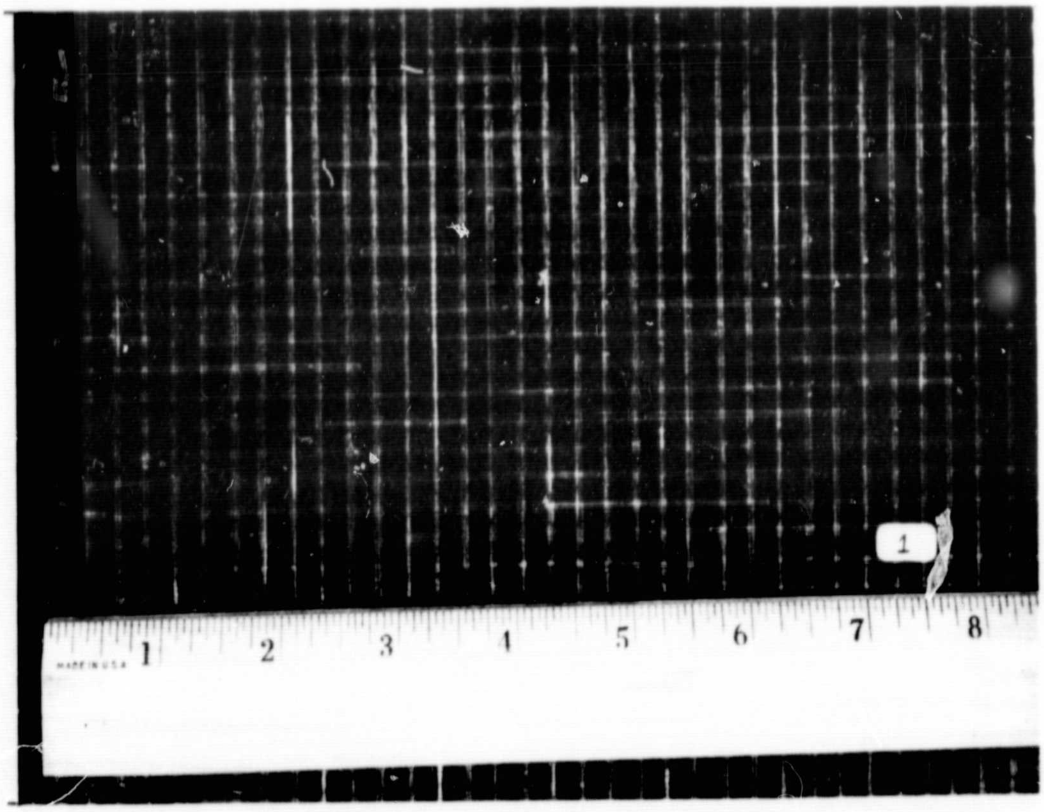
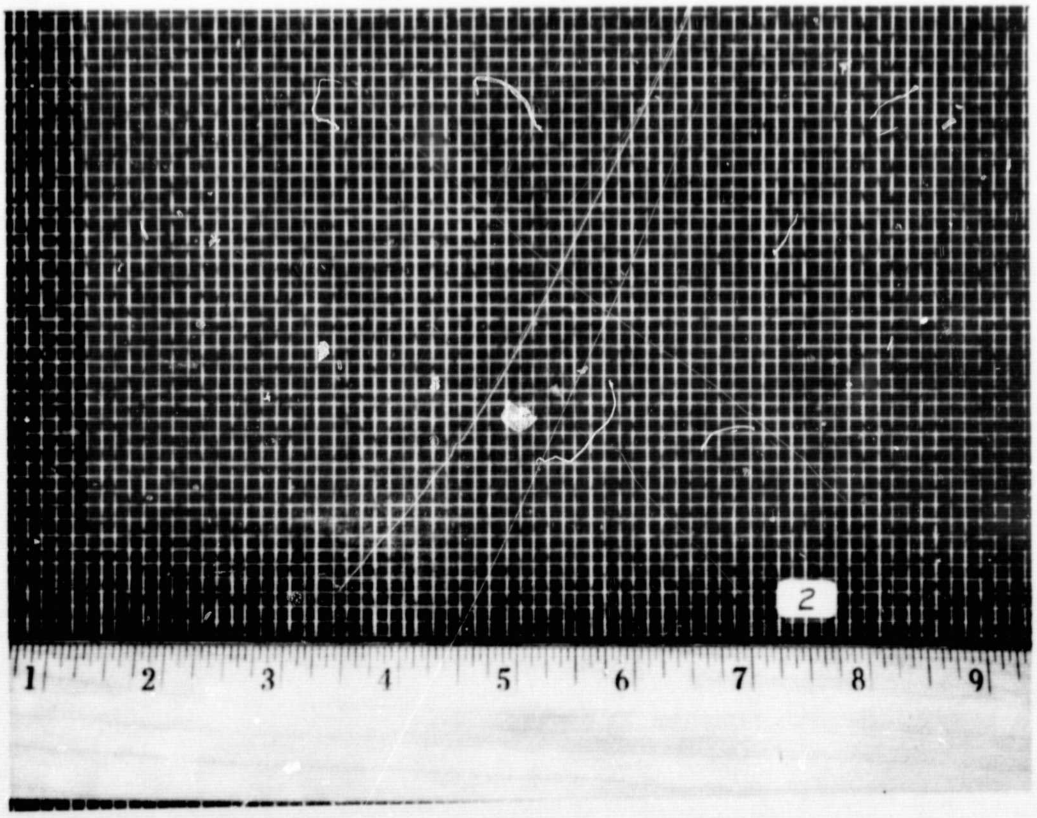


Figure 2

PHASE I - REINFORCEMENT PATTERN - COMPOSITE #2



PHASE I - REINFORCEMENT PATTERN - COMPOSITE #3

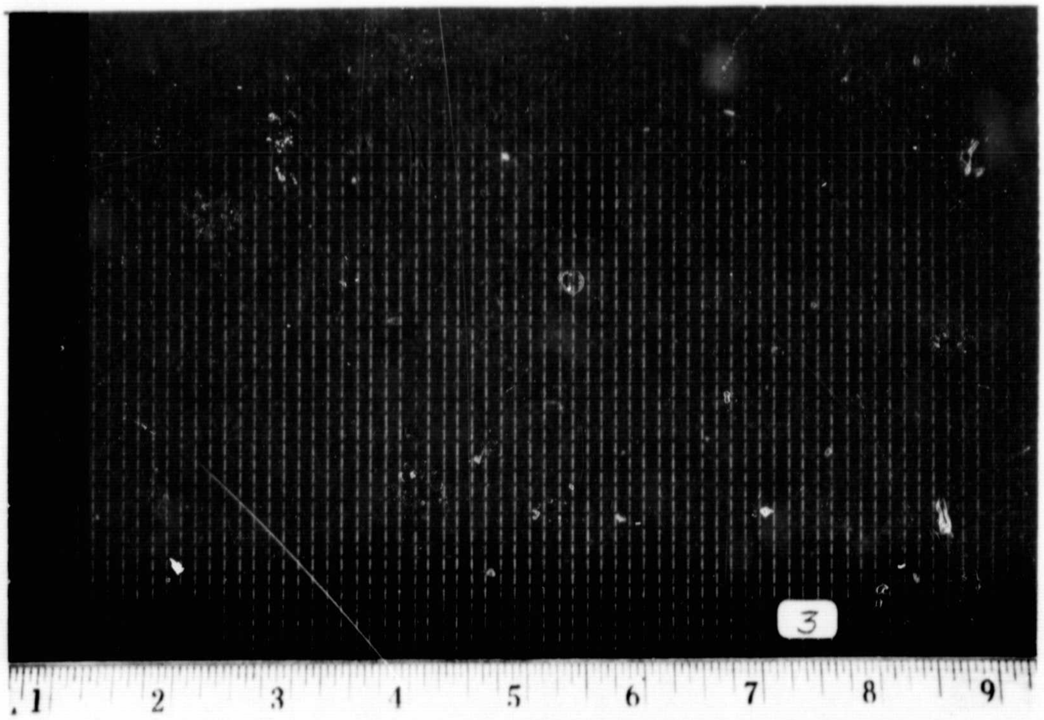


Figure 4

PHASE II - REINFORCEMENT PATTERN - COMPOSITE #4

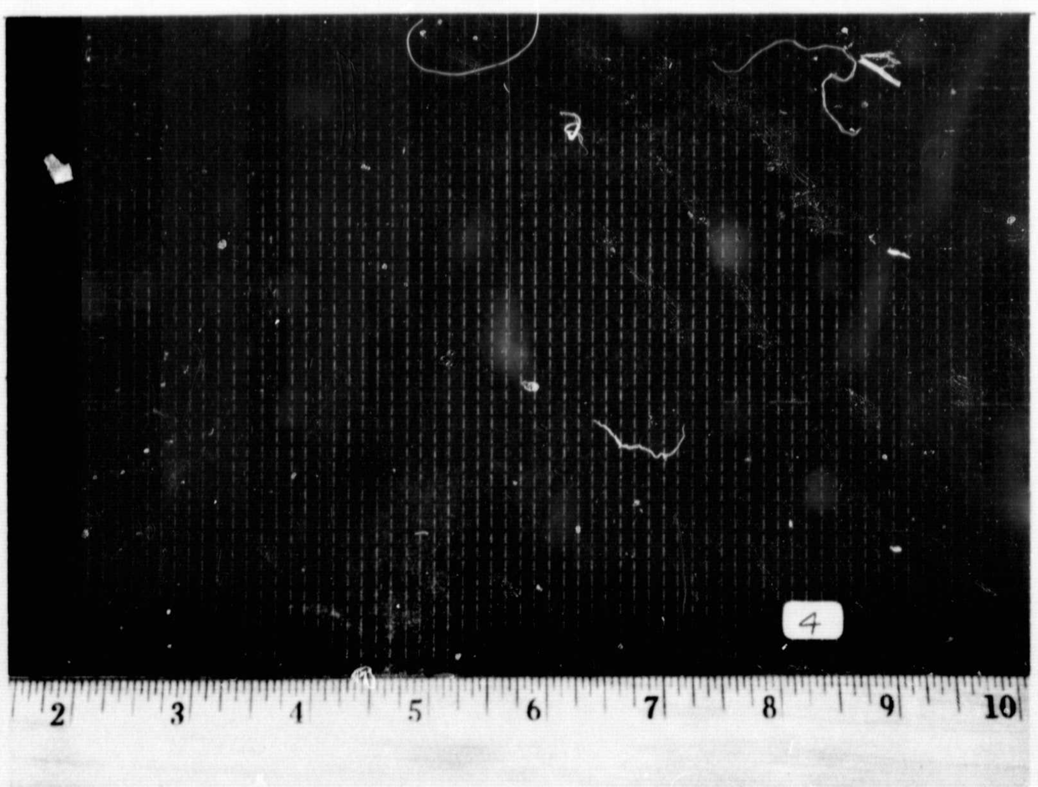
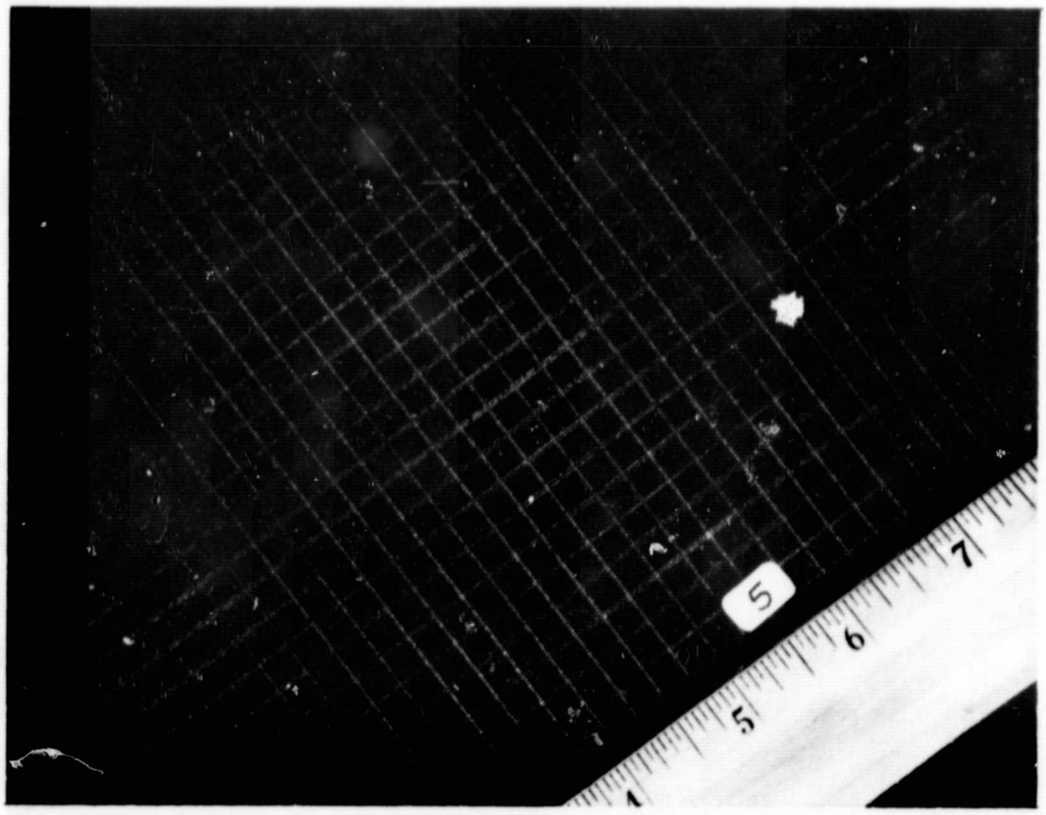


Figure 5

PHASE I - REINFORCEMENT PATTERN - COMPOSITE #5



It should be noted that Estane 5740 x 140 (U-1) which was to be evaluated in the reinforced composites as a potential matrix material was not found to be feasible. The castable Estane formulation consisted of 78% by weight of tetrahydrafuran solvent which upon outgassing created a severe distortion in the reinforced composite.[3]

As revealed in Table 8, reinforced composites 2 and 3 had superior optical properties in comparison with the other constructions. Both of these constructions utilized exterior films of silicone 2 on either side of the

[3] Distortion did not occur in the nonreinforced panels because there was no restrictive element (reinforcement pattern) to obstruct a uniform shrinkage.

Urethane 7 matrix, the addition of which had a pronounced effect on reducing the distortion characteristic in the other three composites. The success experienced with the external films of silicone can be attributed to the 100% solids silicone's ability to even out any surface irregularity[4] which alters the transmission of light through the media.

GAS PERMEABILITY CHARACTERISTICS

Gas permeability tests were conducted on Conathane EN 1554 in order to determine its oxygen transmission characteristics.

The test was performed in accordance with ASTM method D-1434-66. Dry test gas consisting of 100% oxygen was introduced into the cell at the test pressure and the pressure was maintained four to sixteen hours prior to obtaining readings. Two specimens were tested and at least three determinations were made on each specimen. The data reported are average values. The gas was permeated through the specimen, collected in a capillary tube and the time to permeate a specific quantity of gas determined. Tests were performed at laboratory conditions of 23^{o} C.

Sample Identification	Thickness Millimeters	O_2 Transm. Rate*, cc/100 sq. cm. at 23^{o} C, 1 Atmosphere Pressure
Conathane EN 1554 A	2.4892	55.645
Conathane EN 1554 B	2.4638	47.401

* Area exposed in test 65.6128 sq. cm.

[4] The surface irregularity in Urethane 7 - Conathane EN 1554 when cast through a reinforcement pattern is the result of an inescapable need in formulating a 14% by weight quantity of solvent into the compound in order to obtain the desired flow properties. Evaporation of the solvent creates a slight concave meniscus in the open areas of the reinforcement pattern.

PHASE II - PROTOTYPE FABRICATION AND EVALUATION

DESIGN PARAMETERS

The window composites were fabricated, reflecting those designs which evolved from the Phase I development program. Each composite was adhesively attached to a glass fabric carrier panel which in turn was affixed to the side wall of a 122 cm. diameter pressure vessel.[5]

WINDOW COMPOSITE DESIGNS

Four window constructions were selected for evaluation in Phase II. On the basis of the Phase I test results all windows selected consisted of Urethane 7 (Conathane EN-1554) matrices with external films of Silicone 2 (Sylgard 184). Table 9 on Page 24 presents a complete description of the window constructions.

[5] See NASA - CR 66299 "Feasibility Study for Development of a Flexible Reinforced Window"- Figure 20, p. 81.

Table 9

WINDOW COMPOSITE CONSTRUCTIONS - PHASE II

Details	Composite #1	Composite #2	Composite #3	Composite #4
Polymeric Composition	S-2/U-7/S-2	S-2/U-7/S-2	S-2/U-7/S-2	S-2/U-7/S-2
Reinforcement Mat'l	Steel #2	Steel #2	Glass #1	Glass #1
Circumferential Axial	8-2 8-1	4-4 4-2	8-20 8-10	16-10 16-5
Reinforcement Pattern Dimension	3.175 mm x 3.175 mm	6.35 mm x 6.35 mm	3.175 mm x 3.175 mm	1.587 mm x 1.587 mm
Optical Opening In Pattern	2.38 mm X 2.78 mm 6.62 mm^2	4.76 mm x 5.95 mm 28.35 mm^2	2.78 mm x 2.78 mm 7.72 mm^2	1.19 mm x 1.19 mm 1.42 mm^2
Uniroyal Test Panel-Thickness	3.35 mm	3.55 mm	3.27 mm	3.70 mm
Lamina Thickness	0.28 mm/ 2.69 mm/ 0.38 mm	0.41 mm/ 2.64 mm/ 0.50 mm	0.36 mm/ 2.51 mm/ 0.40 mm	0.36 mm/ 3.05 mm/ 0.29 mm
Uniroyal Test Panel-Weight	3.97 Kg/m^2	4.20 Kg/m^2	3.67 Kg/m^2	4.20 Kg/m^2
NASA Sample Panel-Thickness	3.02 mm	2.59 mm	3.47 mm	3.25 mm
NASA Sample Panel-Weight*	3.61 Kg/m^2	3.15 Kg/m^2	3.89 Kg/m^2	3.70 Kg/m^2

* Calculated

ATTACHMENT DESIGN

The incorporation of a urethane material into the flexible window composite as the basic matrix material makes it possible to improve and at the same time greatly simplify the fabrication and installation of the composite into a carrier system.

The excellent adhesion characteristics of the urethane not only to the attachment panel but to the reinforcement pattern makes it possible to eliminate the needs for a separate flange and for anchoring individual reinforcement strands by tying them together beyond the attachment (flange) area.[6]

The actual attachment system is designed to retain the window structure integral with the 122 cm. diameter flexible structure wall system while stressed under 24.3 nscm. internal pressure. The stress developed at the edge of the window when subjected to the normal stresses of the flexible cylindrical vessel does not exceed 1261 n/cm. of cylindrical length or 630.5 n/cm of axial length. Therefore, the attachment system is exposed to this same "pull out" stress load as the actual window composite.

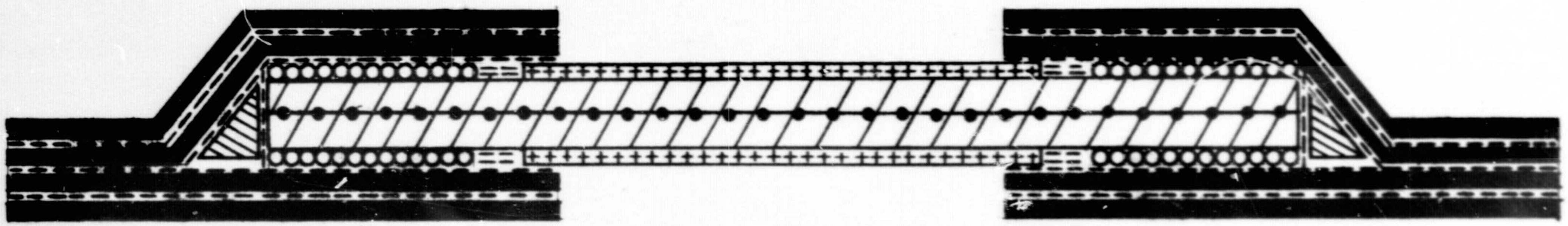
In order to obtain the strength required, a room temperature urethane adhesive was developed to bond the urethane matrix to the actual carrier panel. The adhesive formulation consisted of a 100 gram master batch of a 50-50 mixture of Uniroyal Chemical's Vibrathane 6001 and Methyl Ethyl Ketone, to which 2.5 grams of Uniroyal Chemical's Tonox LC was added.

The carrier panel, as in the previous contract "NASI 5524" consisted of four plies of glass fabric. The fabrication of the actual carrier panel differed from those used previously since the glass fabric was impregnated with urethane #2 (Vibrathane 6004/6007) and was laminated with the room temperature urethane cement mentioned above. Using this same cement, the

[6] See NASA - CR 66299 "Feasibility Study for Development of a Flexible Reinforced Window" - Figure 13, p. 72.

FIGURE 6 DIAGRAM OF PHASE II WINDOW COMPOSITE INSTALLED IN CARRIER PANEL

SINGLE PLY GLASS FABRIC CARRIER CLOTH - URETHANE COATED
URETHANE MATRIX WITH REINFORCEMENT
FIBERGLASS DOILY IMPREGNATED WITH URETHANE CEMENT
RTV SILICONE BONDED TO URETHANE MATRIX WITH SILICONE CEMENT
UNCURED URETHANE NOODLE STOCK - 3.175 mm IN DIAMETER
----- ROOM TEMPERATURE CURING URETHANE CEMENT

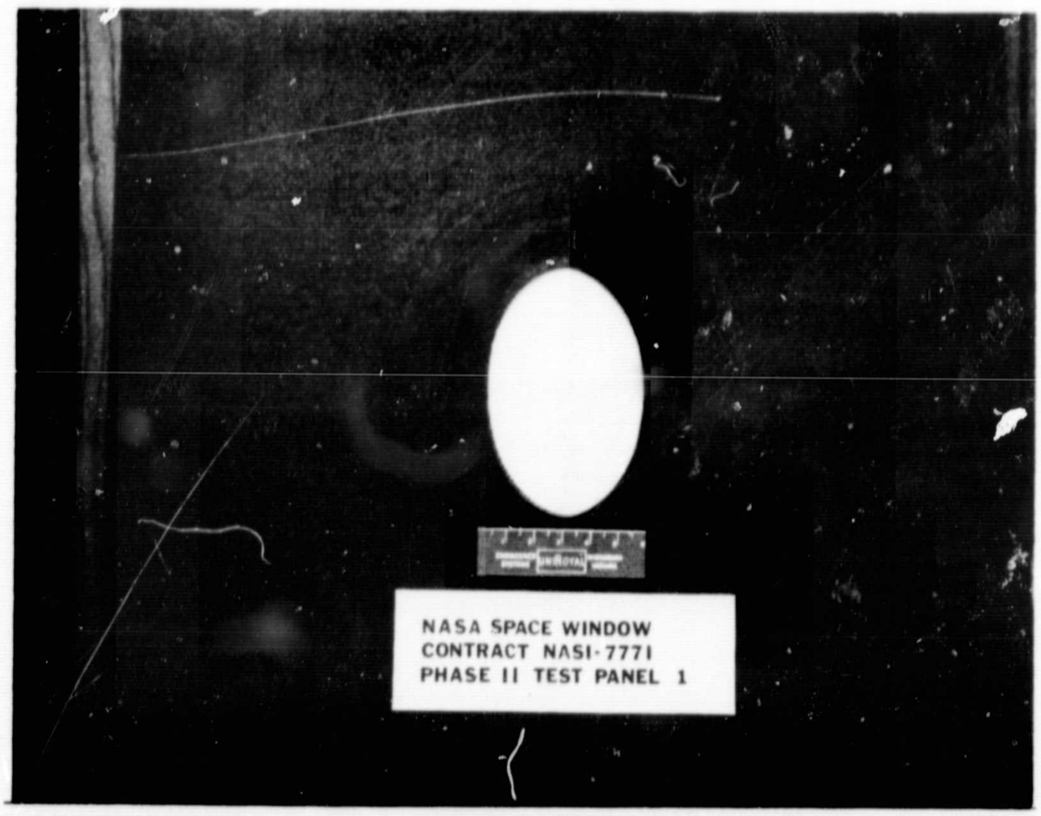


fiberglass reinforcement doilies[7] were bonded both to the carrier panels and to the urethane matrix as diagrammed in Figure 6.

Once installed into the carrier panel (83.8 cm x 83.8 cm) the window (elliptical circumferential - 23.17 cm and axial - 14.52 cm) has an exposed surface of silicone on either side - see Figure 6. The carrier cloth was designed to overlap the edge of the silicone film by 3.175 mm about the elliptical window. Figure 7 represents Phase II window construction No. 1 installed in its carrier panel.

FIGURE 7

PHASE II - FLEXIBLE TRANSPARENT WINDOW INSTALLED IN CARRIER PANEL



[7] The fiberglass doilies were constructed to the same calculated stress load as in the previous contract Ref. NASA CR 66299 p. 65-66.

HUMAN FACTORS OPTICAL TEST

The Human Factors Optical Test is a comparative analysis of the optical clarity of reinforced composites. In this test an eye chart (Figure 8) is placed 24.5 cm. from the test window and the viewer attempts to focus through the window on the eye chart characters (Table 10). Observations are made at various distances from the window and the qualities of the window are rated according to the factors listed in Table 11.

This test was conducted under non-pressurized and pressurized conditions. The results of the test are presented in Table 12.

TABLE 10

CLASSIFICATION OF CHARACTERS ON EYE CHART

Number Sequence	Print Size
0695	6.350 mm
3860	4.762 mm
2439	3.968 mm
8307	2.381 mm
6379	1.785 mm
7860	1.190 mm

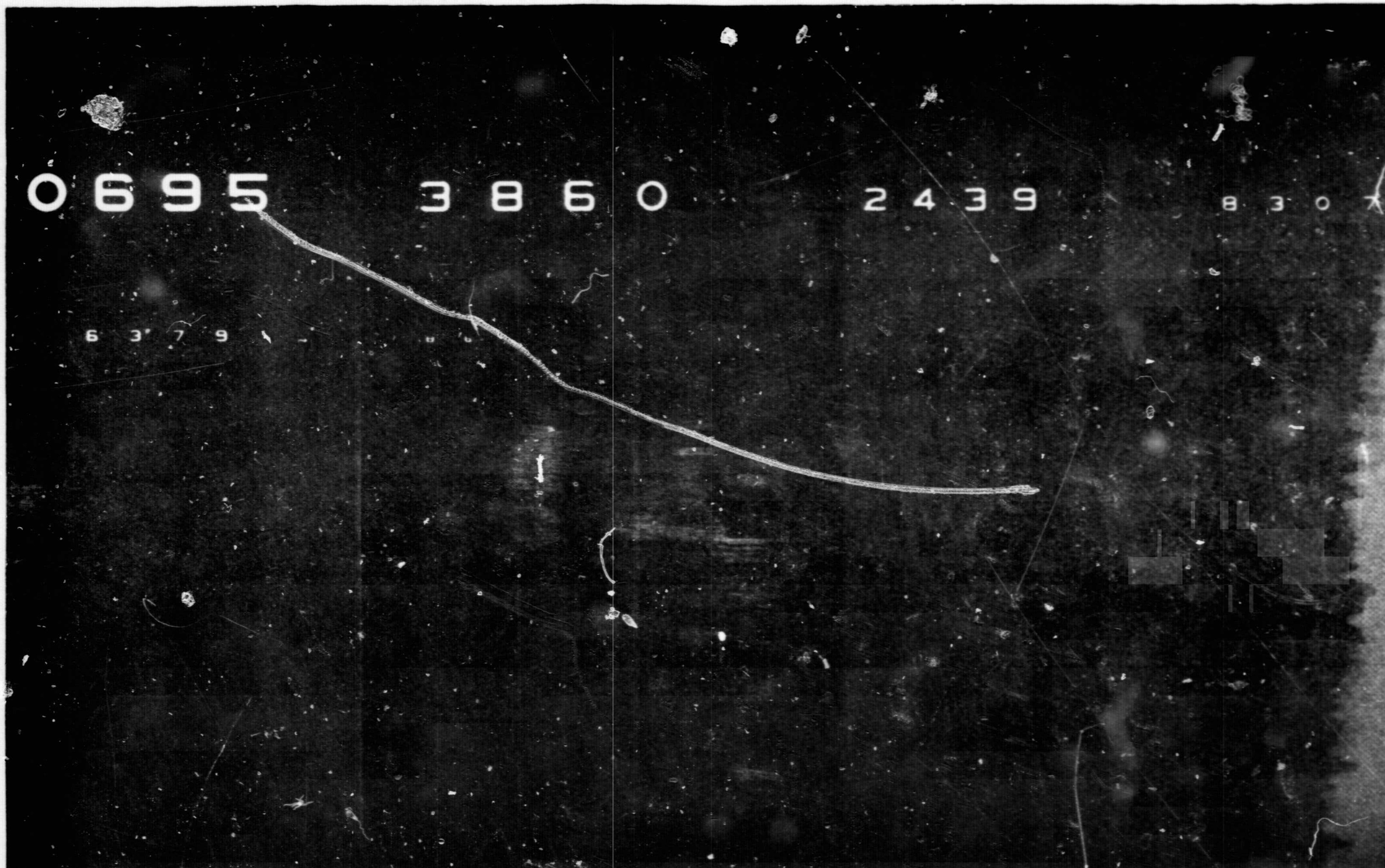


Figure 8 Human Factors Eye Chart

TABLE 11 - HUMAN FACTORS OPTICAL TEST RATING PLAN

A. Blurriness (distortion).

B. Ability to focus.

C. Readibility - (last clear number).

A. Blurriness (distortion).

1. * No distortion.

2.

3. Blurred but still comfortable.

4.

5. Highly distorted, uncomfortable.

B. Ability to Focus

1.* Eyes focus immediately.

2.

3. Strands change focus but still comfortable.

4.

5. Strands interfere with focusing.

C. Readiblity

1.* Reading clear - minimum of magnification disturbance.

2.

3. Letters change magnification but still comfortable.

4.

5. Reading moves with eye movement (high degree of magnification change).

Record last legible number.

* Equivalent to reference of no window present.

TABLE 1

PHASE II - [illegible]N FACTORS OPTICAL AND PRESSURIZATION TESTS

Panel No.		Before Pressurizing			Pressurized to 2.083 NSCM			Pressurized to 4.86 NSCM			Pressurized to 4.86 NSCM - 24 hrs.			Hydro Burst Pressure	Remarks
		EYE DISTANCE FROM WINDOW													
		21 cm	42 cm	84 cm	21 cm	42 cm	84 cm	21 cm	42 cm	84 cm	21 cm	42 cm	84 cm		
1	A	3	2	2	3	2	2	3	3	2	3	3	3		Optically: There was a double image at all pressures. Window Surface: Slight nonuniformity in surface expansion which resulted in a small indentation. Failure: In carrier cloth, not related to window.
	B	3	3	3	3	3	3	3	3	3	2	2	2	24.30 NSCM	
	C	2	2	2	2	2	2	2	2	2	2	2	2		
Last Legible Number		6379	6379	6379	6379	6379	6379	6379	6379	6379	6379	6379	6379		
2	A	1	1	1	2	2	2	1.5	1.5	1.5	1.5	1.5	1.5	22.91	Optically: A slight double image was in evidence which was attributed to one's attempt to focus on a close object interrupted by the reinforcement pattern. Window Surface: Vertical wave in window as follows . The difference in high and low points - 1.587 mm. Failure: In carrier cloth not related to window.
	B	1	1	1	1	1	1	1	1	1	1	1	1	22.91 NSCM	
	C	1	1	1	2	2	2	1	1	1	1	1	1		
Last Legible Number		7860	7860	7860	7860	6379	6379	7860	6379	6379	7860	6379	6379		
3	A	2	1	1	2	1	1	2	1	1	2	1	2		Optically: Double vision was present. Window Surface: The rippling described in Panel 2 was present but with a different pattern . Difference in high and low points - 4.761 mm. Failure: In carrier cloth not related to window.
	B	2	2	2	2	2	2	2	2	2	3	3	3	24.30 NSCM	
	C	2	1	1	2	1	1	2	1	1	2	1	2		
Last Legible Number		6379	6379	6379	6379	6379	6379	6379	6379	6379	6379	6379	6379		
4	A	3	3	4	2	3	4	2	3	4	2	3	4		Optically: Pattern definitely interrupted the clarity of the window. Window Surface: Had the same vertical waves as Panel #2. Difference in high and low points of 1.587 mm. Failure: In carrier not related to window.
	B	3	4	4	2	4	4	2	4	4	3	4	4	20.83 NSCM	
	C	3	3	4	2	3	3	2	3	4	2	3	3		
Last Legible Number		6379	8307	8307	6379	6379	8307	6379	6379	8307	6379	8307	8307		

Note: The eye chart was placed 24.5 cm. from the window composite.

HEAT DEGRADATION

Due to the potential space use of the window there is interest in the potential degradating effect of heat on the window composite and its light transmittance. Table 13 shows the effect on a nonreinforced[8] laminate panel identical in composition (S-2/U-7/S-2) to the four Phase II window composites and having a thickness of 2.286 mm. (S-2- 0.4810 mm/U-7-1.524 mm/ S-2-0.4810 mm).

TABLE 13

EFFECT OF HEAT AGING ON % LIGHT TRANSMITTANCE*

Aging Condition	400 mu	420 mu	490 mu	575 mu	585 mu	642 mu	700 mu
Unaged**	49.0	71.0	89.7	92.0	92.0	92.5	92.7
Aged 1 week - 100^{0} C**	14.0	32.0	77.5	89.3	89.7	91.5	92.5
Aged 240 hours - Ultraviolet**	2.7	4.0	30.7	64.5	67.5	78.7	85.7
Aged 24 hours - 150^{0} C**	4.7	12.5	61.5	83.7	84.7	89.0	91.0

* For test method see Appendix A.

** See Appendix C for complete transmittance curve, Graph No. 1

[8] A nonreinforced laminate panel was utilized in this test program in order to prevent interference effects experienced due to reinforcements interrupting the light beam of the Spectrophotometer.

FLEXIBILITY

Each of the four Phase II window composites was flexed through a 0^{o} - 90^{o} - 180^{o} angle for 100 cycles followed by the opposite (0^{o} - 270^{o} - 180^{o}) angle for an additional 100 cycles. This test was conducted in both the circumferential and axial direction of each composite.

There was no indication of failure in any of the three laminates or in any of the reinforcement patterns among the four panels.

The following pictures provide a comparison of the four Phase II window constructions and reveal the effect of each pattern on the optical transparency. (See figures 9, 10, 11, 12)

FIGURE 9

PHASE II - COMPOSITE 1

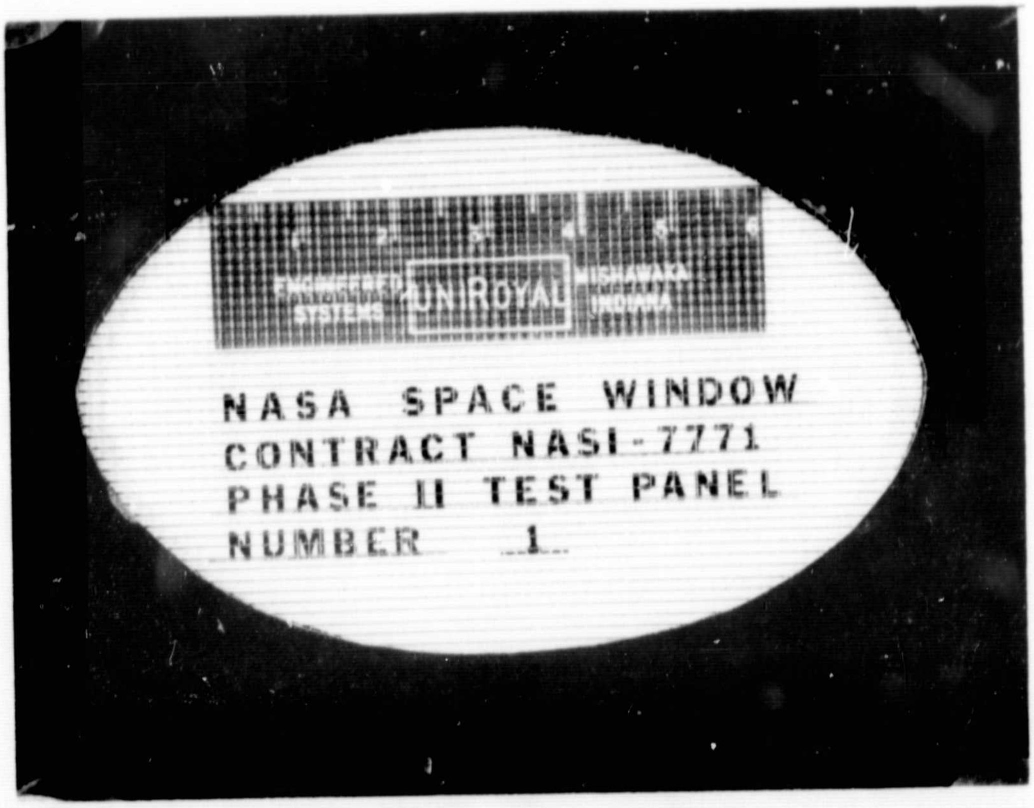
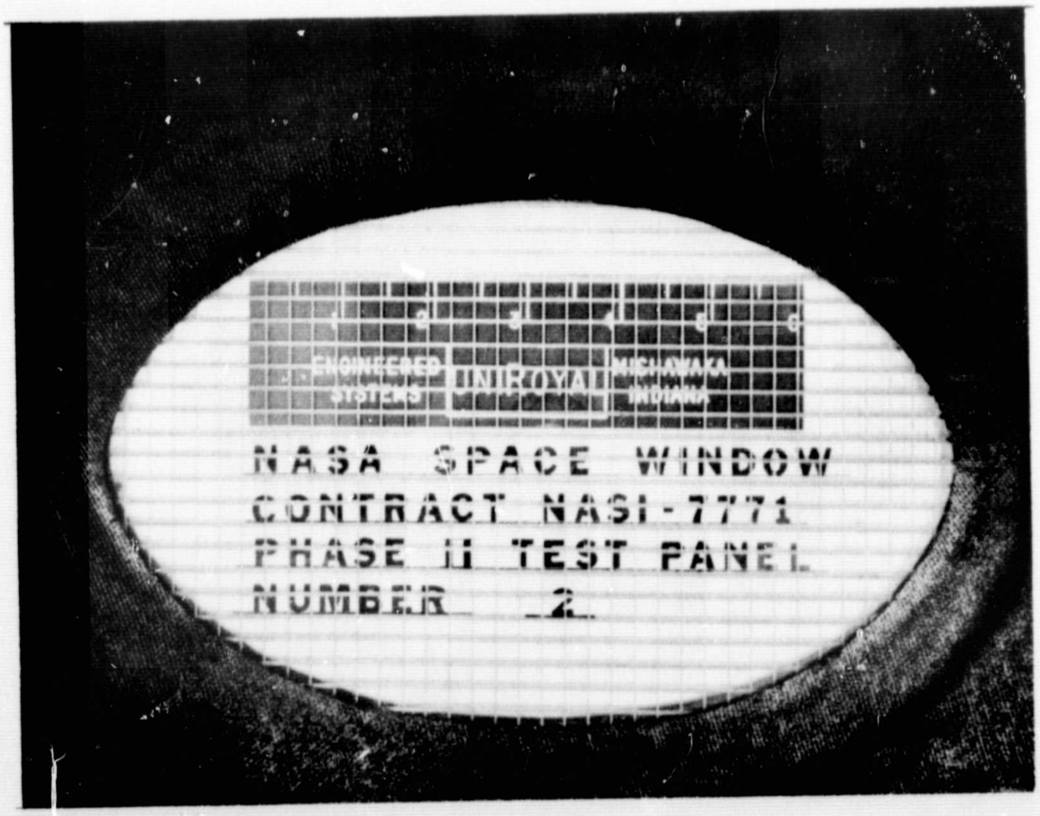


FIGURE 10

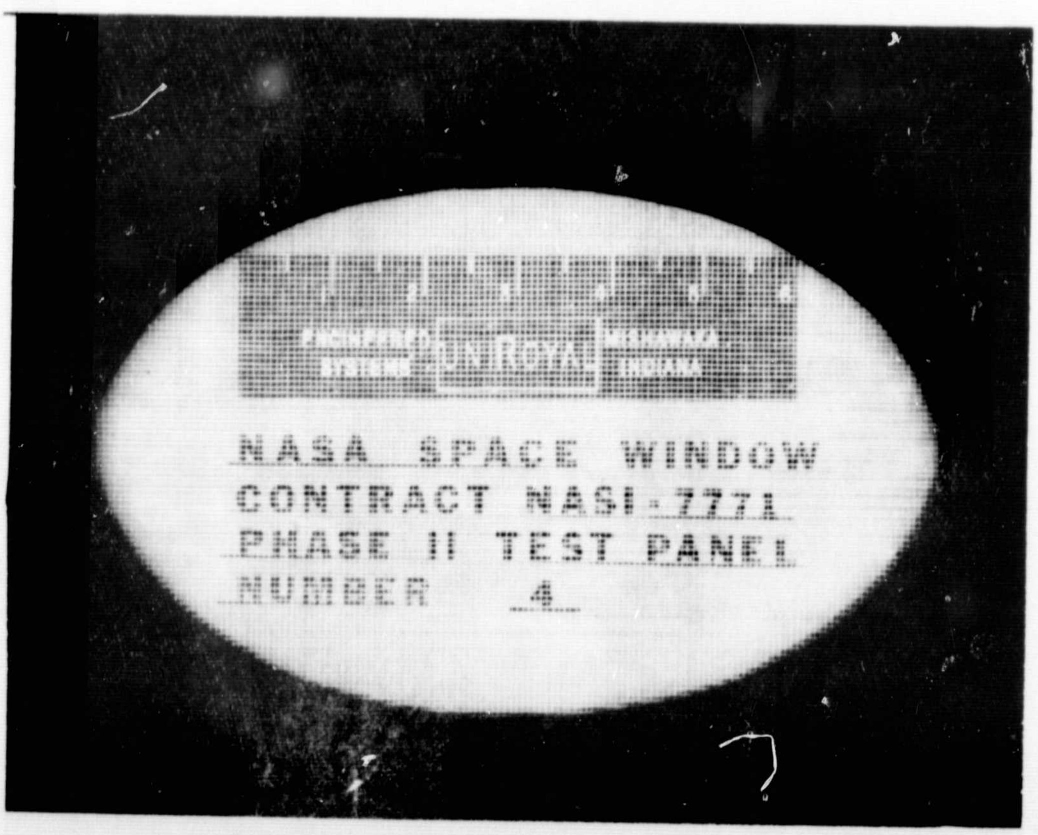
PHASE II - COMPOSITE II



PHASE II - COMPOSITE 3

FIGURE 12

PHASE II - COMPOSITE 4



PHASE II COMPOSITE PRESSURIZATION OBSERVATIONS

As indicated in Table 12 only a slight deflection was observed upon pressurization of the four composite panels. This is indicative of the ability of the urethane matrix system and adhesive system in restricting the window composite. It is significant to note that the deflection was so slight it was not recognizable upon pressurization to failure.

In the "Remarks" of Table 12, an irregularity in the window surface was observed in all four panels upon pressurization. This irregularity was characterized by a vertical waviness in the window area. The waviness was a direct result of uneven tension in the reinforcement pattern; this in turn created an uneven load distribution over the pattern. It is essential, however, to point out that with the exception of Panel 3, the difference from the high to low points in the waviness was only 1.587 mm and also that there was no appreciable effect on the optical transparency of the composites.

There are two contributing factors which account for the overlapping "double image" phenomena observed in the Phase II windows (see Remarks - Table 12).

First, due to the nature of the construction, as the window is pressurized an uneven strain is exerted across the matrix open area. The uneven strain creates a variance in the index of refraction within any given matrix square which alters the rays of the external light source along with the image produced.

A second factor is the obstruction of the reinforcement pattern on the line of vision of the viewer. In the Human Factors Test the optic chart was placed 25.4 cm. from the window. As one focuses through the window on a group of numbers the eye inevitably is forced to focus on a number which is obstructed by a reinforcement strand. Since each eye is viewing from a slightly different vantage point, the exact same image is not recorded. Therefore, the viewer records what appears to be a "double image".

Since Panel 2 was noticeably superior to the other panels in optical properties and also had the largest placement pattern - 6.35 mm x 6.35 mm (thus providing the greatest optical open area within the pattern) it was concluded that the reinforcement pattern size was the most significant element in the complete elimination of the "double image" phenomena.

PHASE III - FILAMENT WOUND STRUCTURE INCORPORATING A FLEXIBLE WINDOW

In this phase, based upon the development efforts of Phases I and II, two flexible window composites were selected to be installed in flexible filament wound pressure chambers.

WINDOW COMPOSITE CONSTRUCTIONS

Upon an analysis of the Phase II test panel evaluation, the UNIROYAL Project Coordinator and NASA Project Engineer concluded that the following window constructions would be fabricated and installed into the flexible pressure chambers (See Table 14.)

TABLE 14 - PHASE III WINDOW CONSTRUCTIONS

Construction	Chamber 1	Chamber 2
Polymeric Composition	S-2/U-7/S-2	S-2/U-7/S-2
Reinforcement Material*	Steel 2	Steel 2
Reinforcement Pattern	6.35 mm x 6.35 mm	12.70 mm x 12.70 mm**
Circumferential	4-4	2-8
Axial	4-2	2-4
Optical Opening in Pattern	5.95 mm x 5.16 mm 30.7 mm^2	9.92 mm x 11.11 mm 110.25 mm^2
Composite Panel Thickness	2.54 mm 0.38 mm/1.78 mm/ 0.38 mm	2.54 mm 0.38 mm/1.78 mm/ 0.38 mm

* The carbon rocket wire cable was selected for both composites because of the inability to construct a low gauge glass reinforced window utilizing the desired patterns.

** Based upon the Phase II Pressurization Observations, although not previously considered in Phase II, there was reason to believe this new (larger) pattern had significant potential in the ultimate flexible window construction.

FLEXIBLE FILAMENT WOUND PRESSURE VESSEL CONSTRUCTION

The dimensions of the flexible chamber are shown in Figure 13. The cylindrical portion of this structure with a diameter of 45.72 cm. was 3/8 the scale of the proposed end application chamber. The dome ends were contoured to yield an isotensoid ovaloid structure.

The chambers were constructed to the same specifications as those chambers submitted to NASA under Contract NASI-5524 (NASA CR 66299).

Since the chambers were identical to those submitted under the previous contract, it was necessary to institute a development program in order to establish a bonding system to adhere the urethane window matrix to the cured nitrile liner. Figure 14 is a cross-section of the system selected for the window attachment. A trial was conducted in order to establish capabilities of the bonding system. Using the bonding system in Figure 14, a trial window was installed into a trial chamber and pressurized. Failure occurred a at a pressure of 47.24 nscm well beyond the required 24.3 nscm. The failure was in the bond area and was attibuted to a reaction of H_2O (used for pressurization) with the resinated nitrile cement. The cement was then adjusted to eliminate its sensitivity to H_2O.

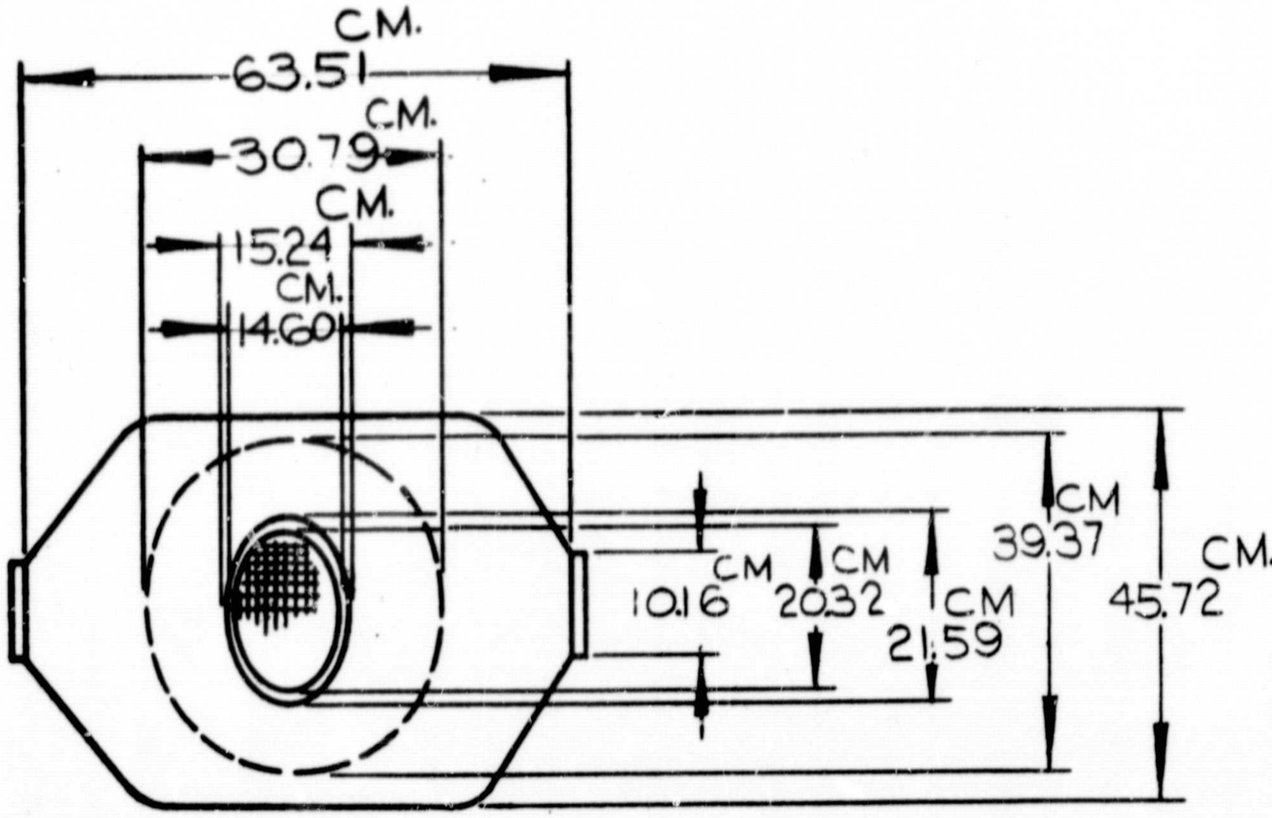
The ability of the actual window composite to withstand pressure in excess of the designed pressure of 24.3 nscm lies in the ability of the urethane matrix to transfer the stress evenly over the entire composite. No direct correlation, however, can be drawn between the trial window and the two chamber windows since the trial window had a smaller reinforcement pattern (3.175 mm x 3.175 mm) and had a greater composite thickness (3.30 mm).

A final conclusion from the trial chamber - window test program is that the window attachment area exhibited sufficient strength. This is significant since two fiberglass doilies were eliminated from the previous contract's total of six doilies in the window attachment area.[9]

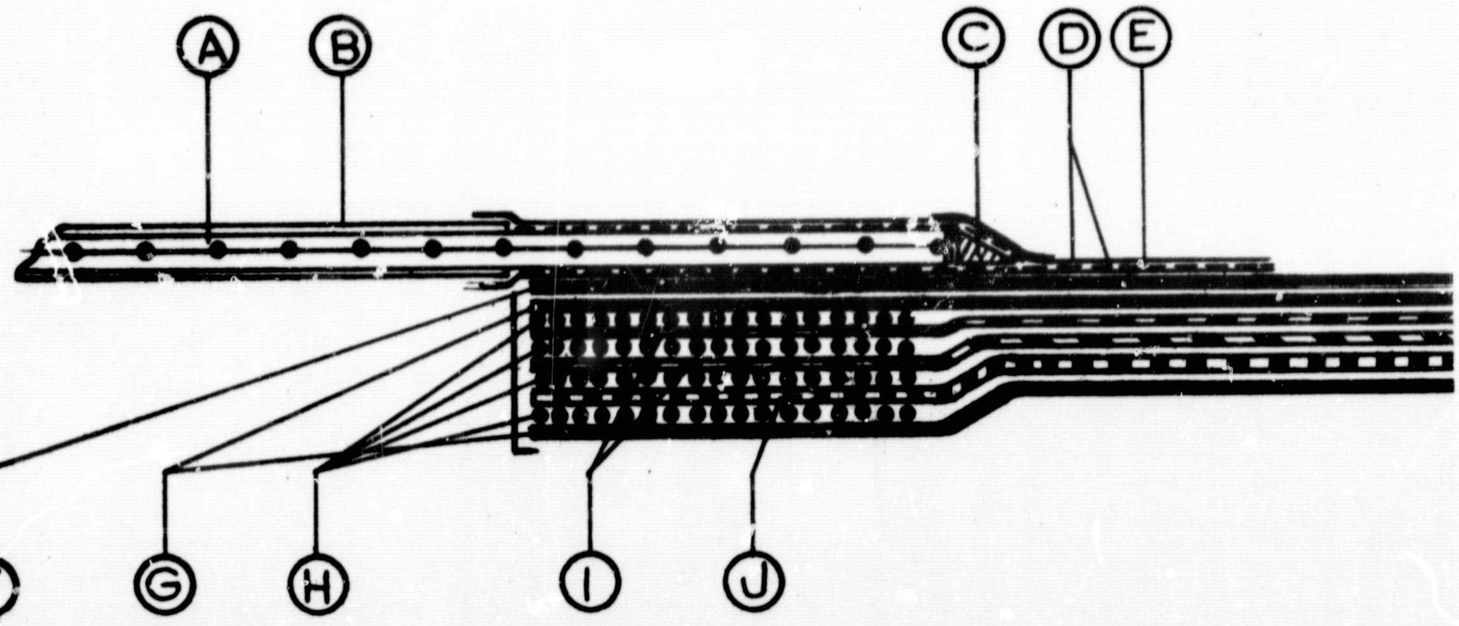
9 The two fiberglass doilies that were eliminated were previously located between "A" and "D" on either side of the matrix in Figure 13B.

FIGURE 13 A-B DIAGRAM OF SCALE MODEL FLEXIBLE FILAMENT WOUND PRESSURE CHAMBER

A.



B.



LEGEND FOR SCHEMATIC STRUCTURAL DESIGN OF CROSS SECTION OF TRANSPARENT WINDOW IN SCALE MODEL CHAMBERS FIGURE 13B

A. Urethane matrix with wire reinforcement.

B. Silicone cover film bonded to matrix.

C. Uncured urethane stock.

D. Urethane coated glass cloth (Phase II carrier cloth).

E. Urethane cement.

F. 56.6 gm. nylon coated with nitrile rubber.

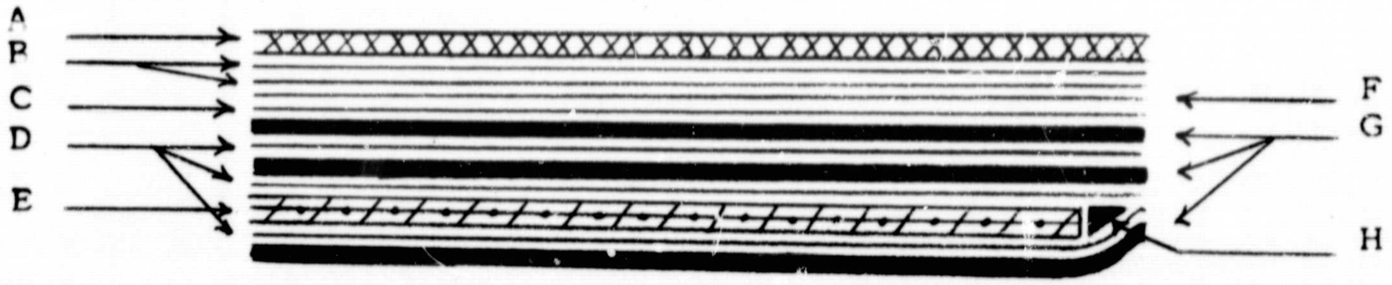
G. Uncured nitrile rubber.

H. Fiberglass doilies embedded in uncured nitrile rubber.

I. First and Second axial plies of elastomer impregnated glass roving.

J. Girth ply of elastomer impregnated glass roving.

Figure 14 Diagram of Window Composite to Chamber Attachment System



A - Cured nitrile coated 56.7 gm nylon (inner surface of chamber)

B - Nitrile cement

C - Liquid nylon

D - Urethane cement

E - Urethane window composite

F - Resinated nitrile cement

G - Urethane impregnated glass cloth (one ply)

H - Uncured urethane stock

Phase III Chamber Proof Test Program

Table 15 indicates those areas in which the two chambers with windows installed, were proof-tested prior to being submitted to NASA.

Table 15 Phase III Chamber Test Program

Chamber No.	Proof Pressure % of Burst	Pressure Medium	Test Pressure	Test Time	Deflection	Window Surface Finish	Window Optic Quality	Human Factors Test
1	20%	Air	4.86 nscm	0	*	*	*	*
1	20%	Air	4.86 nscm	½ hr.	*	*	*	*
1	20%	Air	4.86 nscm	24 hr.	*	*	*	*
1	60%	Air(X)	14.58 nscm	1 min.	*	*	*	*
2	20%	Air	4.86 nscm	0	*	*	*	*
2	20%	Air	4.86 nscm	½ hr.	*	*	*	*
2	20%	Air	4.86 nscm	24 hr.	*	*	*	*
2	60%	Air(X)	14.58 nscm	1 min.	*	*	*	*

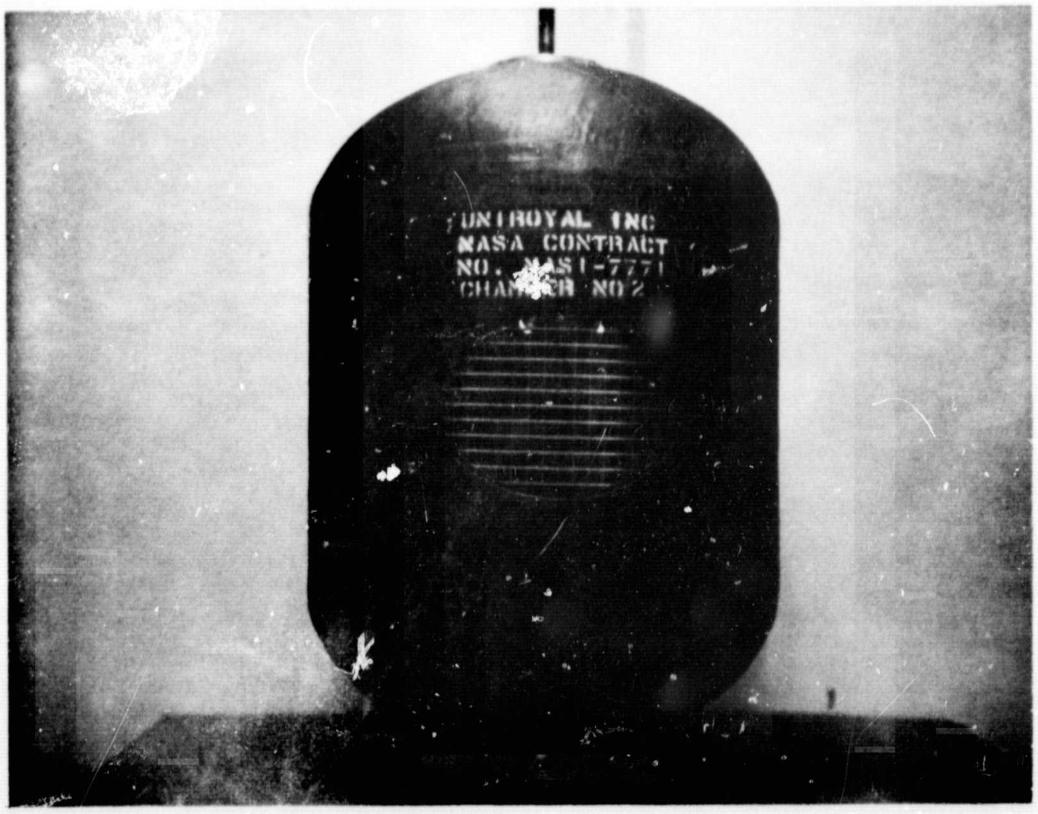
(X) H_2O was previously used as the pressure medium, however, because of the proven reliability of the construction it was not found necessary to use it.

The two window constructions installed into their respective chambers (No. 1 and No. 2) are shown pressurized to 4.86 nscm in Figure 15 A and B.

Figure 15A & B Phase III Chambers Pressurized to 4.86 nscm

A.

B.



CHAMBER PRESSURIZATION

Chamber 1

There was no recognizable effect on the optical properties of the window upon pressurization. The window did, however, orient into a more uniform curvature with the vessel when pressurized. The maximum deflection when pressurized to 4.86 nscm was 3.175 mm after 24 hours and the memory was only 0.794 mm upon releasing the pressure.

Chamber 2

Since the reinforcement pattern in the chamber window had not been evaluated in Phase II it was not possible to predict the window's performance.

In the non-pressurized state, the window in this chamber had a much more uniform surface curvature. This improvement was the result of fabrication modifications adopted in the second chamber/window assembly. The modification consisted of preforming the window composite into the same curvature as the chamber before installation.

Prior to pressurization the optical properties (as predicted) were excellent. When pressurized to 4.86 nscm the matrix exhibited a slight, but recognizable, bulging in the pattern open areas. The window surface took on a quilt-like appearance with a convex meniscus in the open area.[10]

The actual height of any one matrix meniscus was less than 0.8 mm, however, it was sufficient to create a faint overlapping "double image" when attempts were made to focus through the window at a point near a reinforcement strand.

[10] The memory of the window matrix was such that upon relaxation of the chamber, the bulging that occurred during pressurization was not in evidence.

The deflection when pressurized was quite similar to Chamber 1. Upon pressurization to 4.86 nscm the maximum window deflection was 1.5875 mm and after 24 hours at 4.86 nscm was 3.1750 mm. As in Chamber 1 the memory of the window in Chamber 2 was only 0.794 mm.

No adverse effects were witnessed when the chamber was pressurized to 14.58 nscm and held for one minute.

Although window 2 had a larger optical open area in its pattern, when pressurized, window 1 had slightly better optical properties.

It is conceivable that if the matrix were of a higher gauge the bulging that resulted in window 2 would be eliminated in which case it might have the better optical properties.

OPTICAL QUALITIES

Table 16 indicates that both window composites exhibited optical properties superior to any flexible transparent construction previously evaluated.

Table 16 PHASE III Human Factors Test Ratings
(Test conducted in same manner as described in Phase II (pps. 28-31.)

CONDITION*	TEST VARIABLE	CHAMBER #1	CHAMBER #2
Unpressurized	A	1.0 **	1.0 **
	B	1.0	1.0
	C	1.0	1.0
	LAST LEGIBLE NUMBER	7860	7860
Pressurized to 4.86 nscm-1/2 hr	A	1.0 **	1.5 **
	B	1.0	1.0
	C	1.0	1.0
	LAST LEGIBLE NUMBER	7860	7860
Pressurized to 4.86 nscm-24 hrs	A	1.0 **	1.5 **
	B	1.0	1.0
	C	1.0	1.0
	LAST LEGIBLE NUMBER	7860	7860

* Eye chart (Figure 8) located 22.86 cm from window. Observations made at positions 15.24 cm to 30.48 cm from window.

**Average rating for all eye positions.

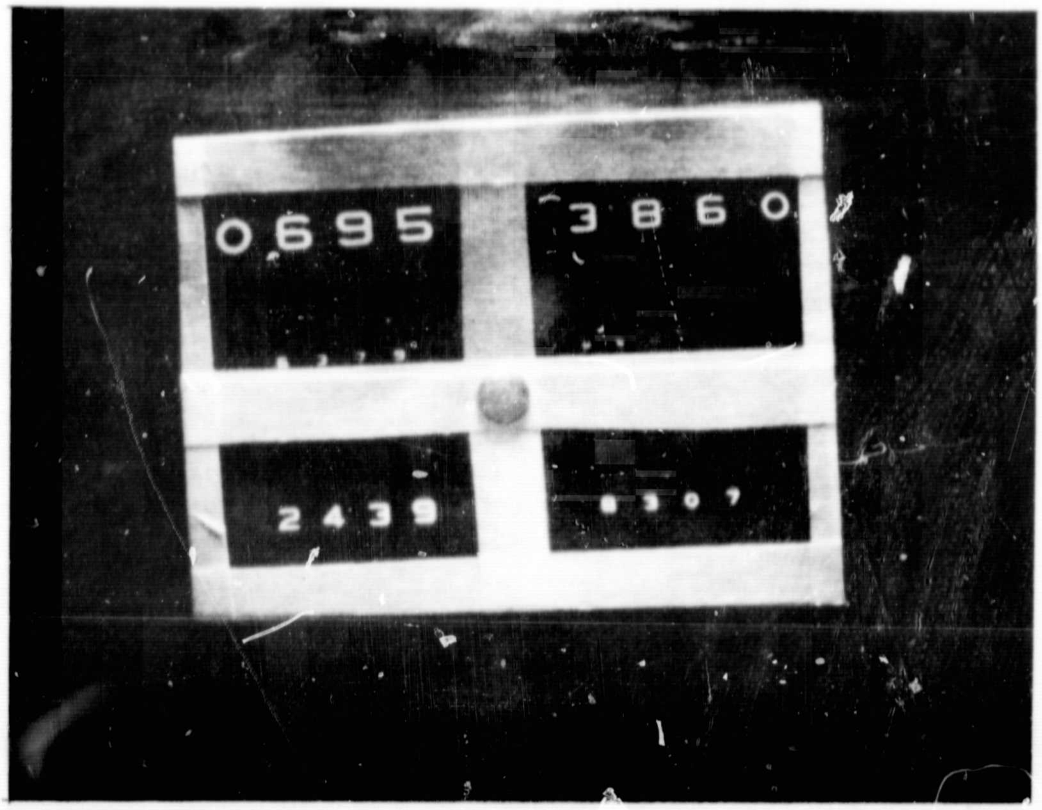
Figures 16 A and B, 17 A and B, and 18 A and B represent three sets of photographs taken during the course of the Phase III prooftesting of the selected windows installed in the two flexible filament wound chambers. In each of the three figures "A" refers to the window composite in Chamber 1, and "B" refers to the window composite in Chamber 2.

Figure 16 A and B represents a view taken from a point 7.6 cm exterior to the chamber. The optic chart in all pictures is located 22.86 cm. from the interior surface of the window composite. Figure 17 A and B represents a photograph taken from a point 15.24 cm to 17.78 cm. (allowance for focusing) exterior to the chamber. In this set the camera was focused onto the optic chart.

Figure 18 A and B represents a photograph taken from the same position as Figure 17 but with the camera focused on the reinforcement pattern.

Figure 16 Phase III Optic Chart Viewed Through Chambers #1 and #2 **Window** Composites Respectively.

A



B

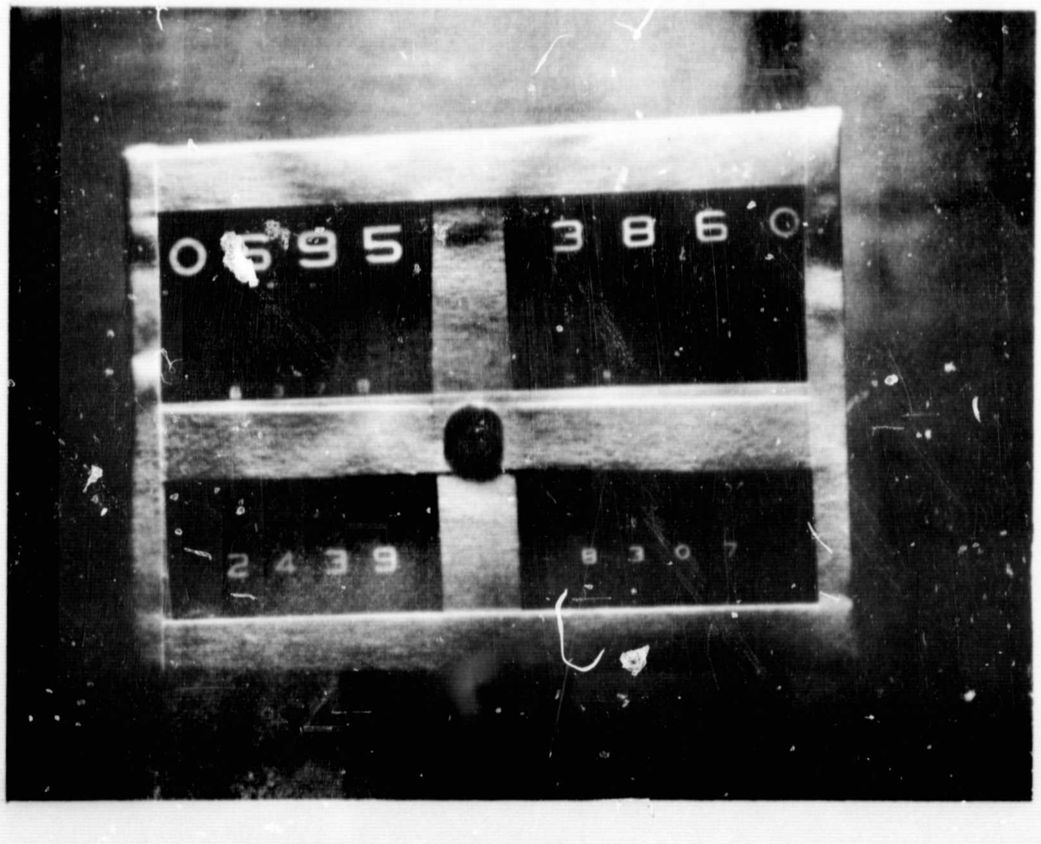
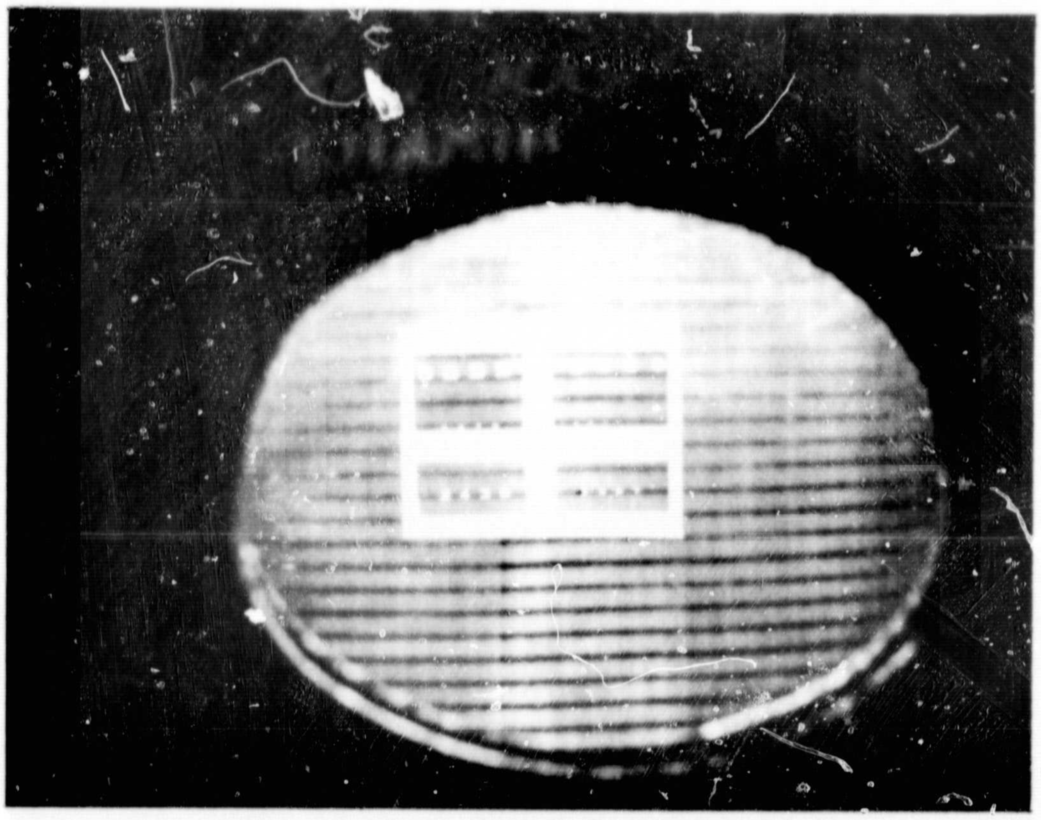


Figure 17 Phase III Optic Chart Viewed through Chambers #1 and #2 Window Compsites Respectively.

A



B

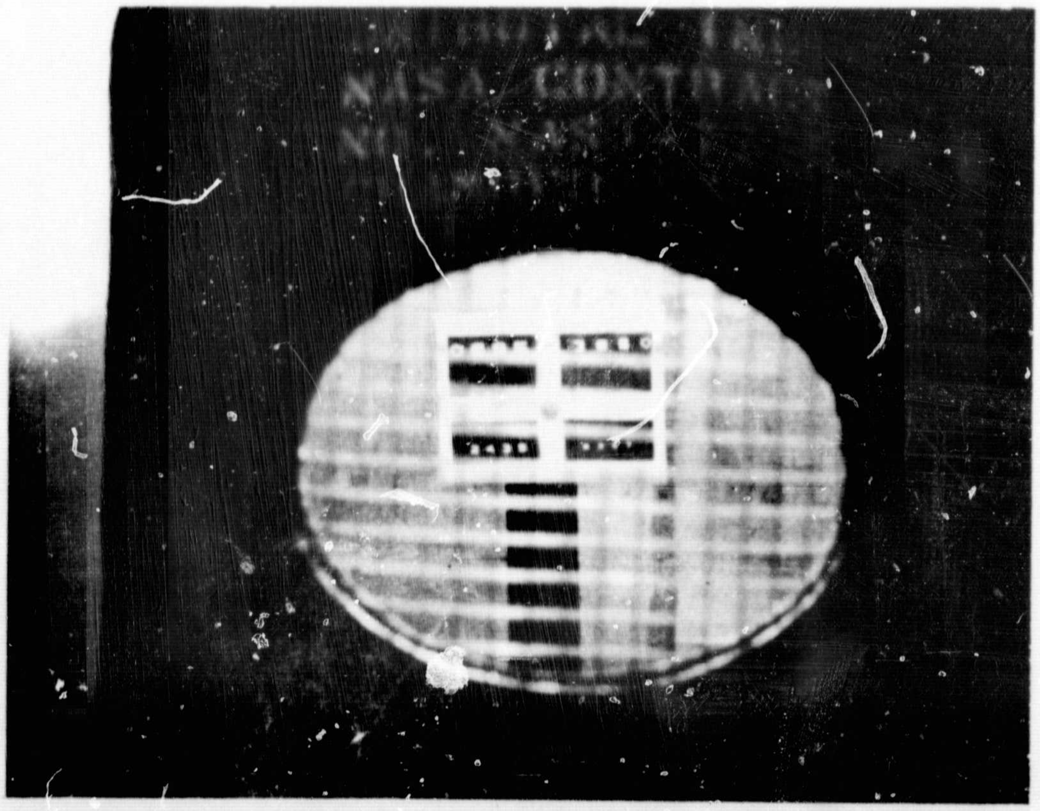
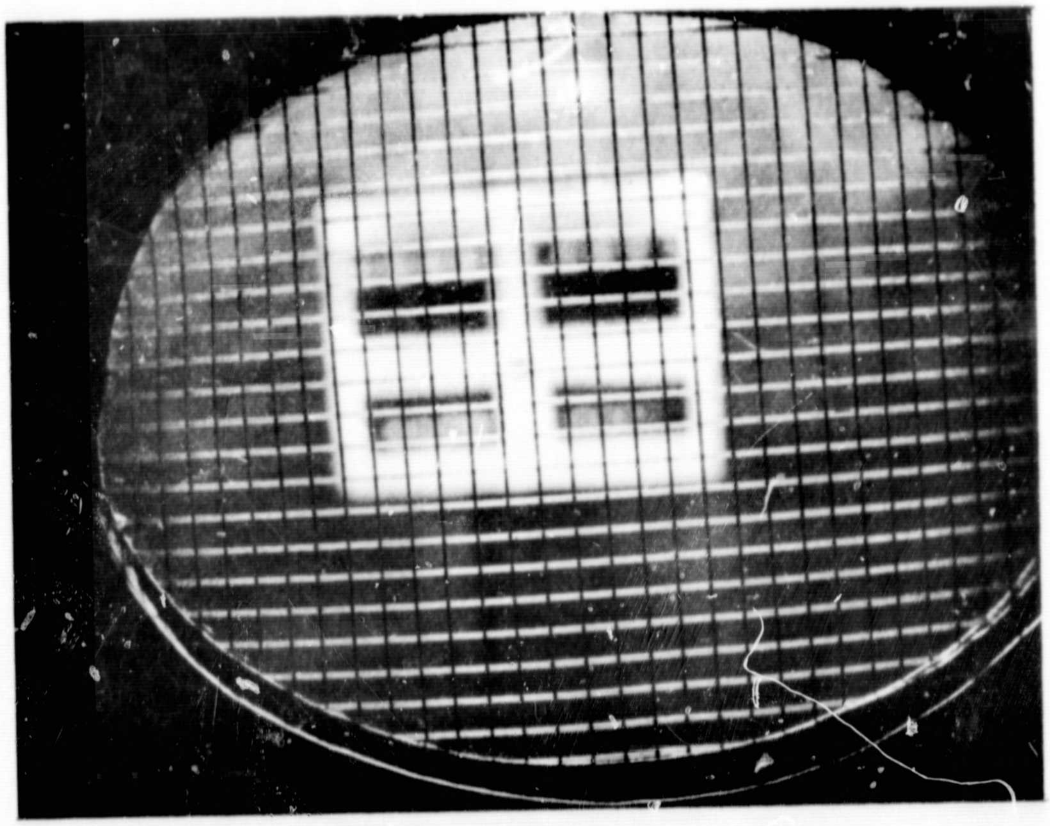
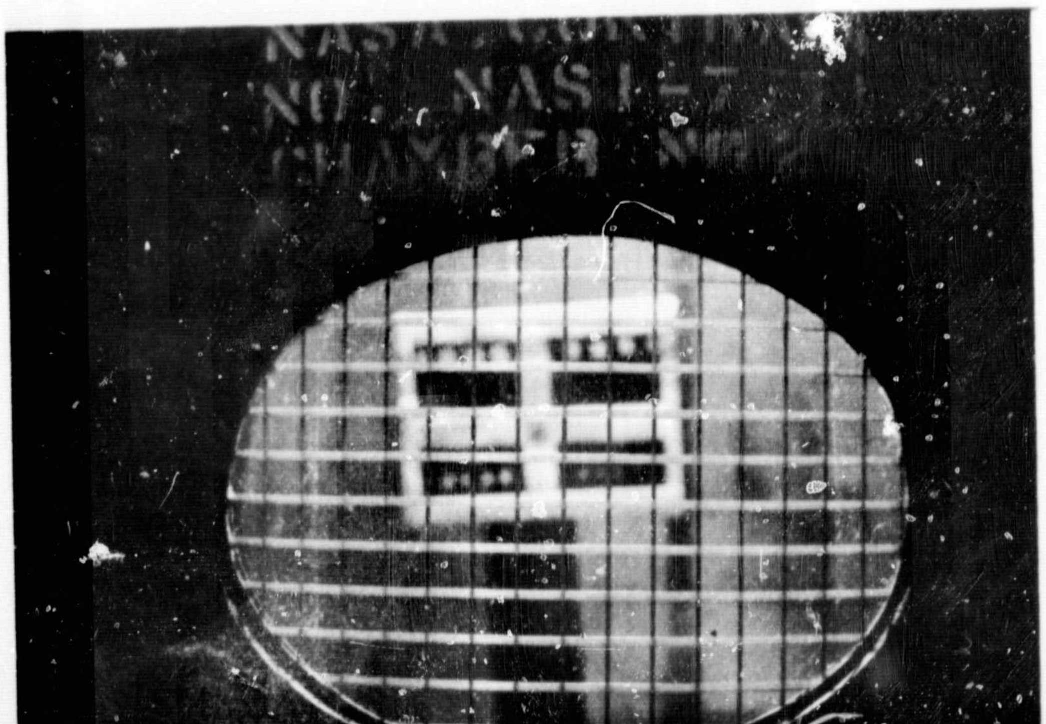


Figure 18 Phase III Optic Chart Viewed through Chambers #1 and #2 Window Composites Respectively.

A



B



The selection of a "large" grid pattern in this contract may be interpreted as contradictory to the conclusions arrived at during the course of the previous contract - NASI-5524.

It must be stated that the most significant reasons for changing to a large grid rests in the selection of a urethane matrix material possessing strength and adhesion capabilities far in excess of the silicone matrix used previously.

Although other factors enter into the selection of the larger grid pattern, this was the most significant in making it possible to fabricate a reinforced composite with larger optical openings and fewer reinforcement obstructions. The later selection of the steel wire as the sole reinforcement material (Phase III) made it possible to fabricate a grid pattern having the minimal total thickness equal to two cable strands (0.6350 mm). This was possible by aligning the strands in a "ribbon" rather than "bunching " them as was inevitable with the fiberglass roving.

The optical success realized in both Phase III window constructions is the direct result of the pattern dimension. With a larger open area in the reinforcement pattern, the observer is able to focus with little difficulty through an individual open area and it is from this phenomena that the larger reinforcement patterns have evolved.

Upon completion of the Phase III Proof-Test Program both chambers 1 and 2 were forwarded to NASA - Langley Research Center.

CONCLUSIONS

Based upon the work conducted in the course of NASA Contract NASI-7771 and the data contained within this report, the following conclusions may be drawn:

A. A transparent reinforced/polymeric composite capable of being utilized as a flexible window in space vehicles was fabricated.

B. It is possible to utilize the reinforcement pattern/polymeric matrix as the attachment medium for incorporating a window into a flexible structure.

This system does not require the anchoring of indiv' ıal reinforcement strands and has been proof tested to 48.60 nscm internal pressure.

C. A polyether urethane matrix provides the window transparency,strength,and bonding capabilities necessary in the window composite.

D. Satisfactory materials for use in fabı icating transparent, flexible windows consist of brass-plated carbon steel cable (as reinforcement) embedded in a matrix of a castable polyether urethane which in turn had a castable dimethyl R.T.V. silicone laminated on both sides.

E. The urethane matrix encapsulated in the R.T.V. silicone does not succumb to the adverse effect characteristic of polyurethane upon exposire to ultraviolet light.

F. The high strength steel filament provides a low gauge reinforcement pattern which permits a thinner overall window composite.

G. Those reinforcement patterns having the larger open areas provide the better optical properties (12.7 mm x 12.7 mm and 6.35 mm x 6.35 mm vs. 3.175 mm x 3.175 mm and 1.587 mm x 1.587 mm). This is based upon the ability to focus through individual openings in the pattern.

H. The R.T.V. silicone when cast in a low gauge film -0.254 mm to 0.381 mm is capable of withstanding severe flexing which is not characteristic of the same material in higher gauge films.

RECOMMENDATIONS

During the course of our work in the development of an improved flexible reinforced transparent composite for use as a window in space vehicles several areas considered worthy of future study became apparent.

1. Evaluate the use of an open pattern woven fabric as a reinforcement strength member.

2. Work toward development of a flexible, transparent, composite having a maximized open area netting pattern; minimized thickness; developing optimum design.

   NOTE: Tests conducted during the course of this contract have revealed that the final window composites possessed pressure capabilities in excess of the required load of 24.30 nscm.

3. Evaluate a flexible, window composite installed in a highly flexible chamber designed to withstand an internal pressure load comparable to that of the actual window.

4. Develop methods of fabricating complete cylinders of transparent composites.

5. Evaluate the application of "Photoelastic Techniques" to the study of strain patterns in the reinforced polymeric transparent panels. (See NASA CR 66299.)

APPENDIX A

STANDARD TEST METHODS

1. Aging Test Conditions

One Week Aging at 100°C.

Test samples 6" x 6" were aged for one week at 100°C in a circulating hot air oven. Samples were suspended in the oven, which was electrically heated, in order to assure uniform penetration of heat throughout.

Ultraviolet Radiation

Test samples were aged for 240 hours in accordance with ASTM procedure D-750-55T. Test samples 3" x 6" were placed in a fixture, in an unstrained condition, and exposed to the effect of light having essentially the same wave lengths as found in natural sunlight but with increased intensity in the ultraviolet range. Temperature, within the exposure unit utilized, was held at 68° ± 2°C. as measured utilizing black panel temperature.

Test specimens were subjected to "UV" exposure for 240 hours (10 days) in an Atlas Fadeometer, Model #18-F. Based upon the calculations, presented below, 240 hours in the Fadeometer are equivalent to the "UV" exposure experienced during 29 days in orbit.

Factors Used in Calculations:

1. Approximately 9.03% of the sunlight outside of atmosphere is below 0.4μ wavelength and may degrade materials. ("Space Materials Handbook", 2nd edition, Technical Documentary Report ML-TDR-64-40, Page 33 "Solar Spectral Irradiance Data").
2. 33.9 watts/ft^2 below 0.4μ is produced by the Fadeometer. ("Atlas Fadeometer Brochure", 1962, Page 6.)
3. Solar Constant - 442 BTU/Hr - (Mark's Mechanical Engineers Handbook, 6th Edition.)

STANDARD TEST METHODS

1. **Calculations:**

Required Exposure = (30 days) (24 hrs/day) (442 BTU/Hr.) (0.0903)

RE = 28,737 BTU/FT^2

Fadeometer Exposure = (240 hrs.) (33.9 $Watts/Ft^2$) (3.413 BTU/Watt hr_2)
FE = 27,768 BTU/Ft^2

Fadeometer Exposure Equivalency = $\frac{27,768}{28,737}$ (30 days) = 28.99 days

2. Material Test Methods

A. Light Transmittance

The light transmission qualities of the polymers, in sheet form, were determined over the full range of the visible spectrum (380 mμ - 700 mμ) utilizing a General Electric "Recording Spectrophotometer". The "Recording Spectrophotometer" consists of three essential units - the monochrometer, the photometer, and a recorder. The monochrometer breaks up the white light into the spectrum colors, each at a band width of 10 millimicrons. The photometer system illuminates the sample (either by transmittance or reflectance) with monochromatic light and furnishes a measurement signal of this light to the recorder.

The "Recording Spectrophotometer" provides a curve which is a complete and exact specification. The instrument can be used where it is desired to measure color in the visible or near ultraviolet region of the spectrum.

The entire visible spectrum range is encompassed between the 400 mμ and 700 mμ wave length limits tested. The respective wave length bands selected for tabulation in Tables 13, 18, and 22 cover the following continuous spectrum:

Wave Length Range* (mμ)	Color
400 - 424	Violet
424 - 490	Blue
490 - 575	Green
575 - 585	Yellow
585 - 647	Orange
647 - 700	Red

* Note: Maximum visibility in daylight or brilliant artificial light is at 556 mμ.

B. Flexibility Test

This test was performed using a "Bally Flexometer" manufactured by Bally's Shoe Factories, Ltd., Schndenenwerd, Switzerland.

A. Instructions for Use of Bally Flexometer

1. The specimen, Figure 19A is folded along its center line in the longitudinal direction, so that the side to be observed is turned inside. The specimen is clamped according to Figure 19B into the clamp until the stop and the screw is tightened.
2. The protruding part of the specimen is turned inside out downwards over the clamp, so that the bending edge runs vertically downwards. (See Figure 19C.)
3. The free end of the specimen is put without tension in the fixed clamp and the screw tightened. (See Figure 19D.)
4. The counter is put at zero by pressing down the lever in the motor. The apparatus provides 100 flexings a minute.

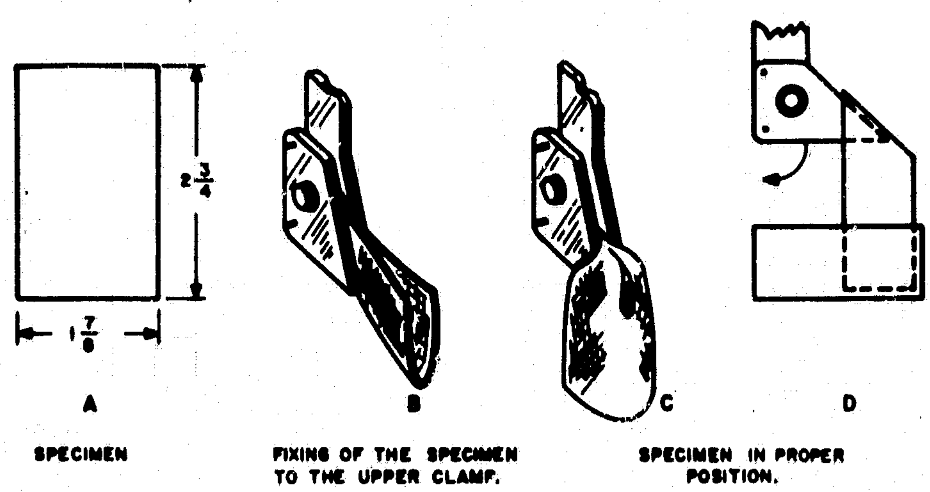


Figure 19. Bally Flex Testing Procedure

B. Procedure

The specimen is controlled frequently during the first hour, afterwards only hourly.

1. Examination of the finish:

   After 1000 and 10,000 flexings the motor is stopped and the finish is observed for appearance of cracks.

2. Examination of the sample itself:

   The number of flexings until the sample breaks is determined.

C. Surface Finish

Surface finish was a visual test performed on all samples. The films were cast against highly polished chrome-plated steel plate having a 1/2 RMS finish with the exception of the U-7 films which were cast against a cured film of RTV dimethyl silicone. All samples as cast exhibited a clear surface. After aging, many of the urethane samples exhibited crazing, or opacity as noted in tables 6 and 11.

D. Stress-Strain (Elongation vs Tensile Strength)

This test was performed utilizing an Instron test machine operating at a jaw separation rate of 30.48 centimeters per minute. The test was run in accordance with ASTM method D412-64T utilizing die "C" having a 6.35 millimeter constricted area. Specimen strain was measured manually. Test results are shown in Tables 17 and 21.

APPENDIX B

TABULATED TEST DATA

TABLE 17

PHASE I POLYMER EVALUATION

ELONGATION VS TENSILE STRENGTH (nscm)*

(For graphic presentation of the values below see Graph No. 15 - Appendix C)

Polymer	Description	100%	200%	300%	400%	500%	600%	700%	800%	900%	1000%	1100%	BREAK
U-1	Estane 5740x140	483	634	785	966	1213	1509	1832	2143	2505	2872	3167	3167
U-7	Conathane EN1554	286	366	476	622	816	1042	1271	1550	-	-	-	1782
S-2	RTV-Sylgard 184	396	-	-	-	-	-	-	-	-	-	-	597

* For test method - See Appendix -A 2-d

TABLE 18 PHASE I POLYMER EVALUATION
% LIGHT TRANSMITTANCE *

GENERAL ELECTRIC RECORDING SPECTROPHOTOMETER **

UNAGED, AGED 1 WEEK AT 100° C, AGED 240 HOURS ULTRAVIOLET

		UNAGED	AGED	AGED	WAVE LENGTH *						
Poly-mer	Thick-ness		1 Week 100°C	240 Hr. UV	400 mu	420 mu	490 mu	575 mu	585 mu	642 mu	700 mu
U-1	2.29mm	X			18	51	79	82.7	82.5	84.3	85.7
U-1	2.29mm		X		4	9	49	64	65.5	78.5	82.[illegible]
U-1	2.29mm			X	6	15	58	75.7	77	81	83.3
U-7	2.16mm	X			42	59.	86.3	90.5	90.7	91	91
U-7	2.16mm		X		46	60	82	87.5	88	88.5	88.5
U-7	2.16mm			X	2	5	32.7	67	70	79.5	83
S-2	2.29mm	X			93	94.5	95.7	94.5	95	94.7	94.7
S-2	2.29mm		X		75.7	80	87.5	90.3	91.	92	92.5
S-2	2.29mm			X	88	90	92	92.5	92.5	92.5	91.5

* See Appendix-C for Transmittance Curves Graphs No. 2 through 4

** For Test Method see Appendix A

TABLE 19 - PHASE I. POLYMER EVALUATION
BALLY FLEX TEST*

Polymer	Thickness	Number of Flex Cycles
U-1	1.52 mm	470,545 Cycles - Test Terminated - No Failure
U-7	1.778 mm	579,067 Cycles - Test Terminated - No Failure
S-2	1.651 mm	Sample Cracked Prior to Initiation of Test

*For Test Method See Appendix 2-B.

TABLE 20 - PHASE I. POLYMER EVALUATION
VISUAL QUALITY TEST

	COMMENTS		
Polymer	Unaged	Aged 1 Week at 100°C	Aged 240 Hours - Ultraviolet
U-1	Clear (Light Amber)	Clear (Amber)	Slightly Crazed
U-7	Clear (Light Amber)	Clear (Amber)	Crazed and Opaque
S-2	Clear	Clear	Clear - No Change In Clarity

TABLE 21 PRIME BARRIER FILM CANDIDATES

ELONGATION VS TENSILE STRENGTH (nscm)*

Number	Description	Thickness	ELONGATION 50%	100%	150%	200%	250%
1	Teflon C-20	0.1295mm	1,335	1,362	1,471	1,580	-
2	Aclar	0.1168mm	3,171	3,171	3,171	4,229	-
3	Kel-F	0.1295mm	(30%) 5,141	-	-	-	-
7	Kapton 200F919	0.0508mm	(40%) 11,115	-	-	-	-
7	Kapton 500F	0.1193mm	13,154	-	-	-	-

*For Test Method See Appendix 2-D.

Table 22 NON-REINFORCED LAMINATE PANELS - % LIGHT TRANSMITTANCE*

Condition	Panel No.	400 mu	420 mu	490 mu	575 mu	585 mu	642 mu	700 mu
Unaged**	1	57	74	84.5	85.5	85.5	86	86.3
	2	47	64	85.3	89.5	89.5	90.5	90.7
	3	92	93.7	95.3	95	95	94.5	94.5
	4	32.5	51	80.3	83.5	84.5	85.5	86.7
	5	23	41.5	78.5	87.5	87.5	88.5	89.5
	6	58.5	70.3	86	88.5	88.5	88.5	89
	7	41	61	85	90.5	90.7	90.7	91.5
	8	54	65.5	81	86.7	87	87.5	88.5
	9	52.5	49.5	65	78	78.5	81	84.7
	10	84.5	85.5	88	88	88	88.3	89
Aged 1 Week** at 100°C	1	13	18	60	71	72	81	84.5
	2	10.5	24.5	64	80	80.5	84.3	86
	3	75	80.5	88.3	90.5	90.5	90.7	91.3
	4	24	40.5	74	85	85.5	88	89.3
	5	4	12	49.5	73.5	75.5	81.3	85.5
	6	8.5	16.7	60.5	70	71	81	85
	7	11	24.5	63	80.5	81.5	85.7	88.5
	8	9.5	22	60	77.7	78.7	83	85.5
	9	1.5	1	1.5	11.5	12.5	22.5	50
	10	74	80	88	89	89	89.5	90.5
Aged 240 Hours** Ultraviolet	1	4	15	57	78	79	83.3	85
	2	2	2.5	24	60	63	76.5	82
	3	80	89.5	93.5	93.3	93.3	93.3	93.3
	4	8	22.5	62	79.5	80.5	84.5	86.5
	5	2	1.5	10.5	42	44.5	62	75.5
	6	2	2.5	24	63	66	78	83.5
	7	2	2	18	53	57.5	73	82.7
	8	2	1	4	18.5	19	24	62
	9	2	2	2	16	19	35	57
	10	80	84	89.5	90	90	90	90.5

* For test method see Appendix A

** See Appendix - C for transmittance curves.

Graphs No. 5 thru 14

APPENDIX C

The following graphs contain the complete light transmittance curves as recorded on the General Electric Spectrophotometer. Superimposed on each graph are the curves for one construction after exposure to the environmental conditions as indicated.

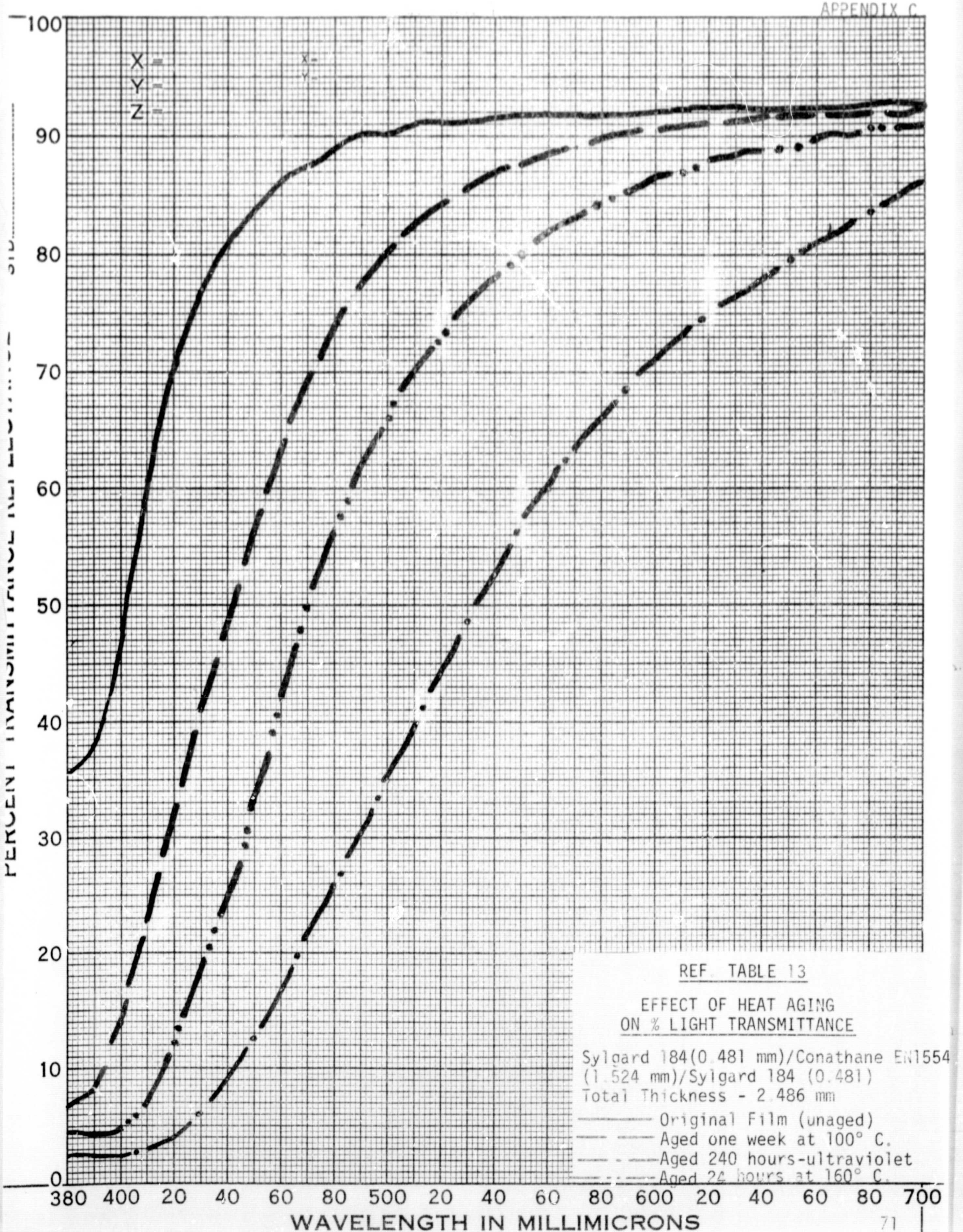
Each graph is referenced to a table previously referred to in this report

Graph No. 1 - Reference Table 13

Graph No. 2 thru 4 - Reference Table 18

Graph No. 5 thru 14 - Reference Table 22

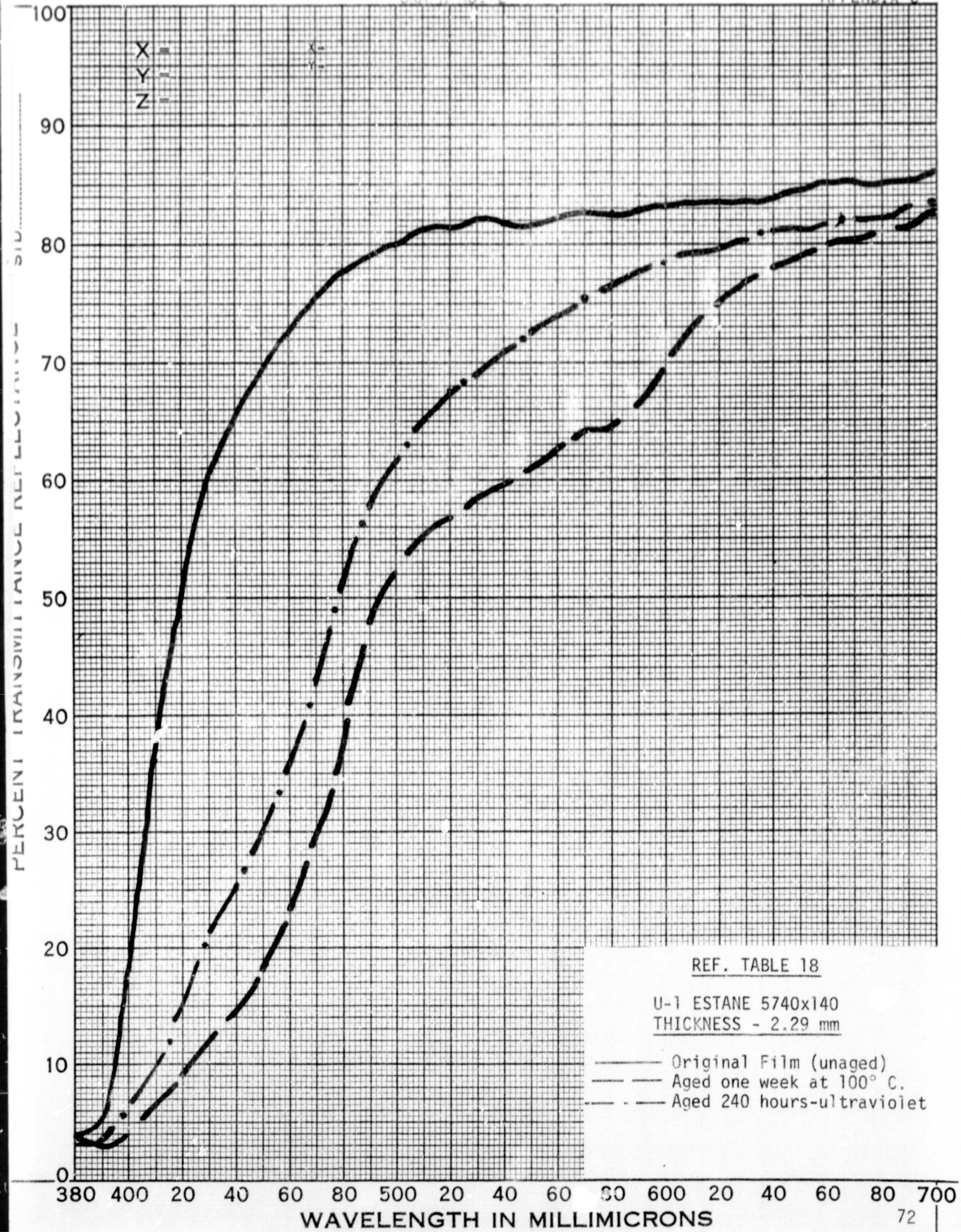
Graph No. 15 - Reference Table 17



REF. TABLE 13

EFFECT OF HEAT AGING ON % LIGHT TRANSMITTANCE

Sylgard 184(0.481 mm)/Conathane EN1554 (1.524 mm)/Sylgard 184 (0.481)
Total Thickness - 2.486 mm


PERCENT TRANSMITTANCE REFLECTANCE
STD.
X =
Y =
Z =
100
90
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70
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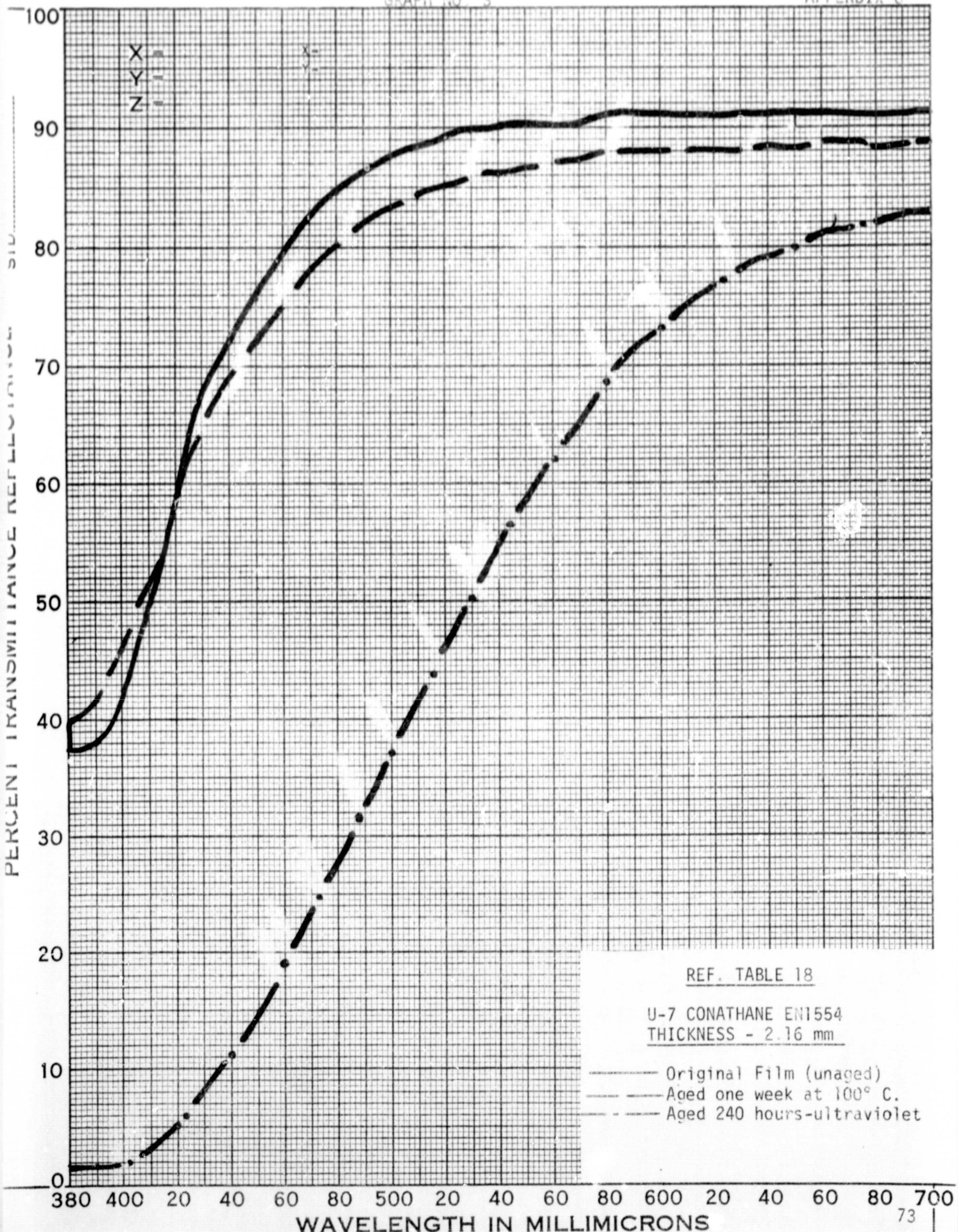
10
0
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 18
U-1 ESTANE 5740x140
THICKNESS - 2.29 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet


PERCENT TRANSMITTANCE REFLECTANCE STD.
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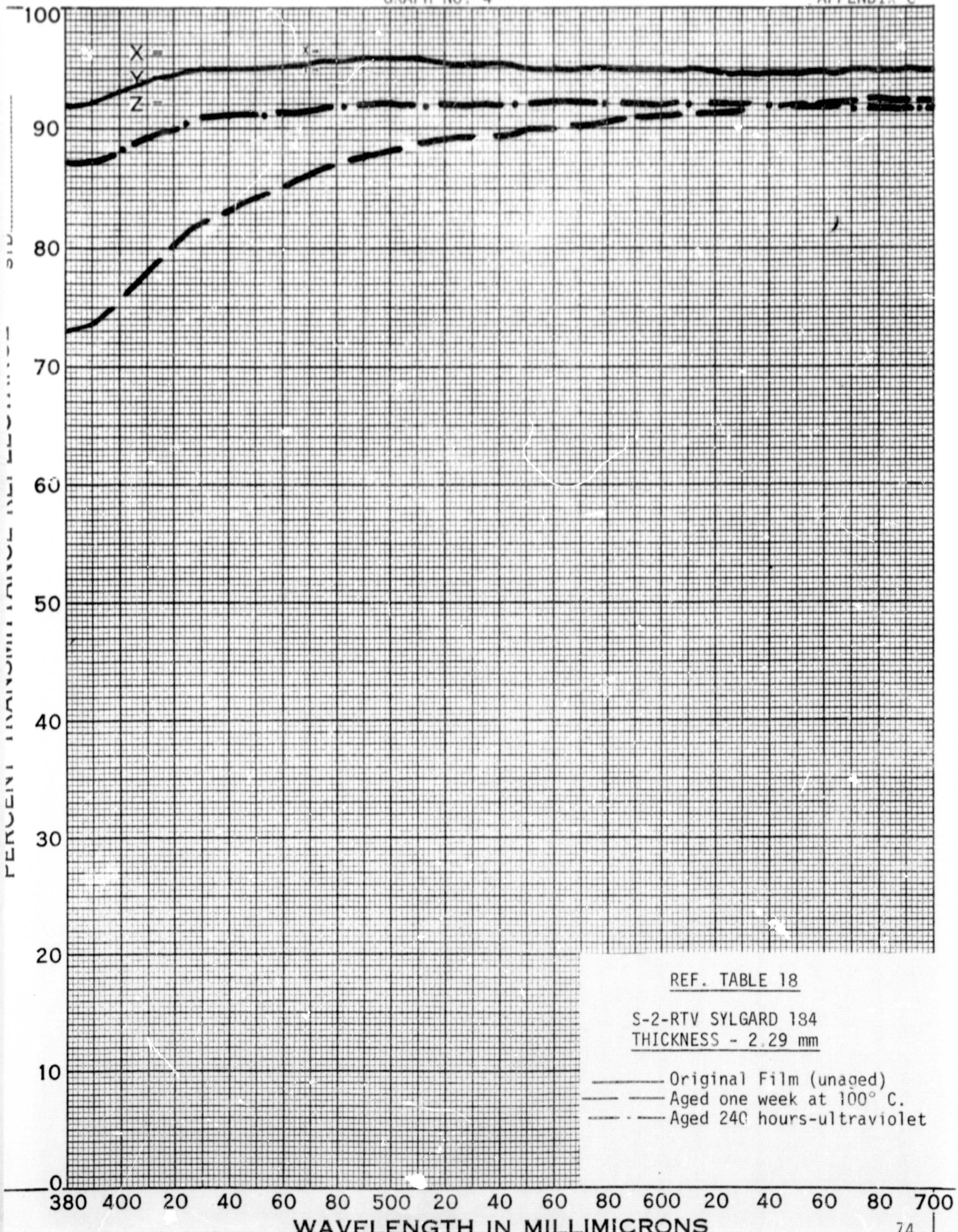
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 18
U-7 CONATHANE EN1554
THICKNESS - 2.16 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet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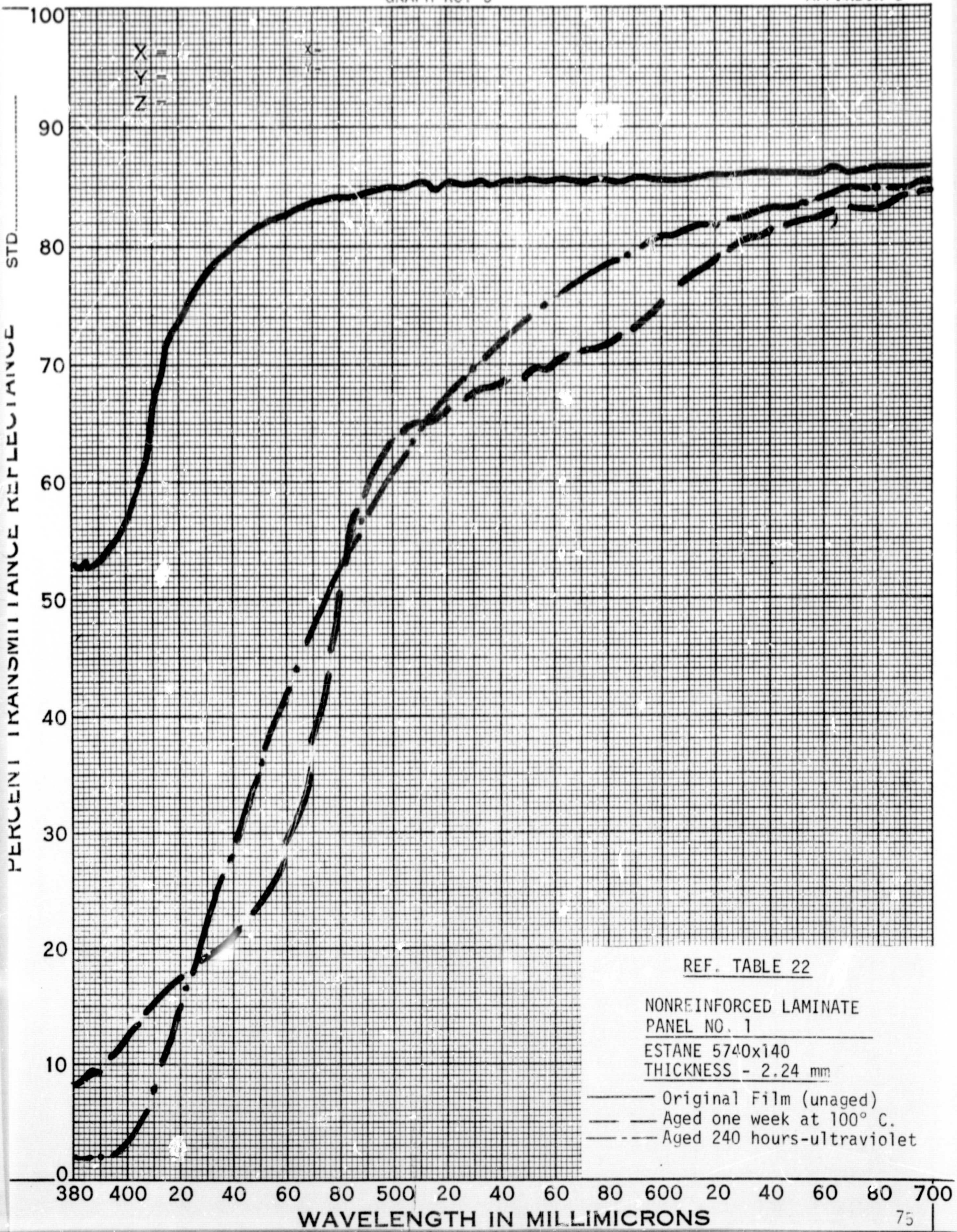
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 18
S-2-RTV SYLGARD 184
THICKNESS - 2.29 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet


PERCENT TRANSMITTANCE REFLECTANCE
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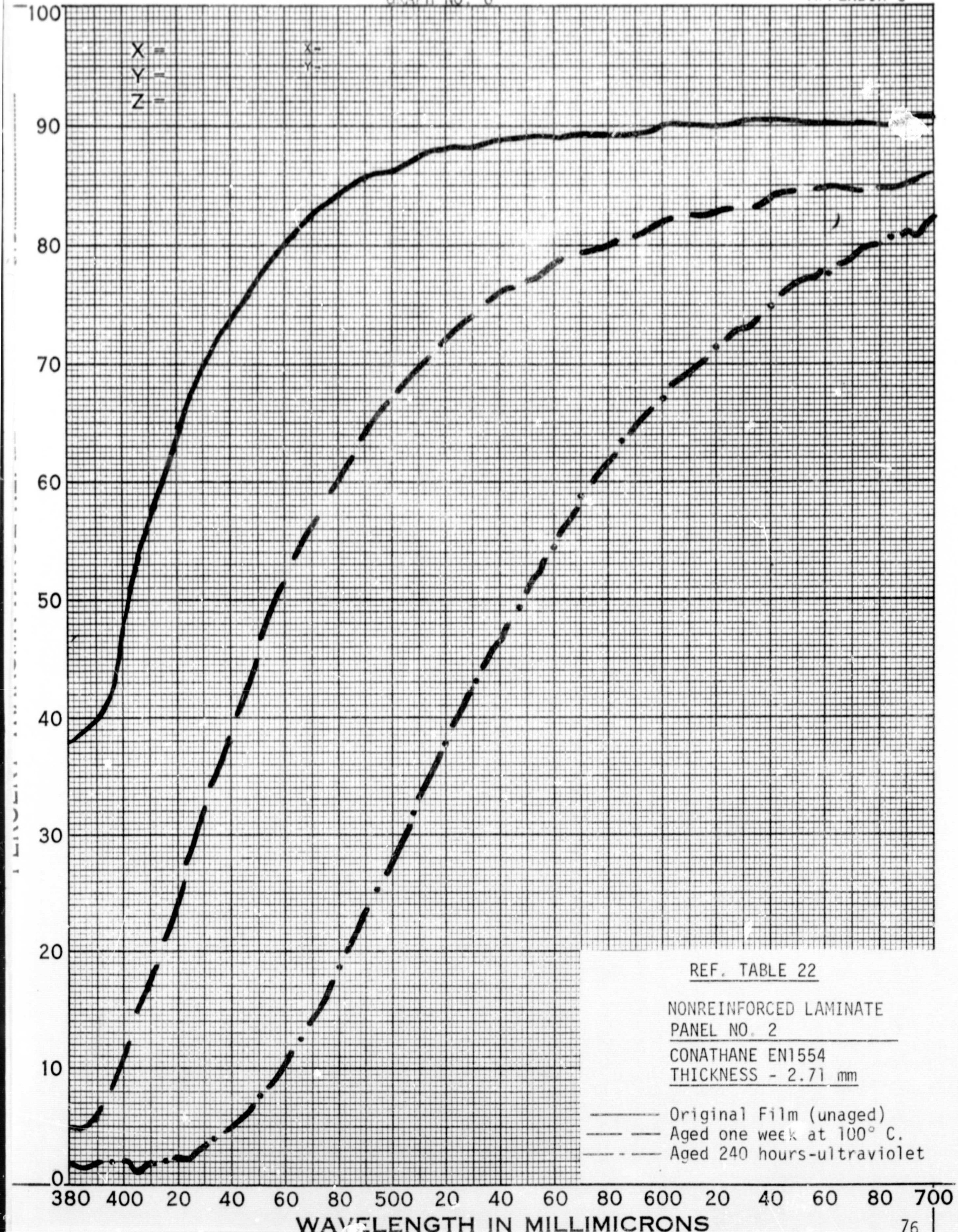
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 1
ESTANE 5740x140
THICKNESS - 2.24 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet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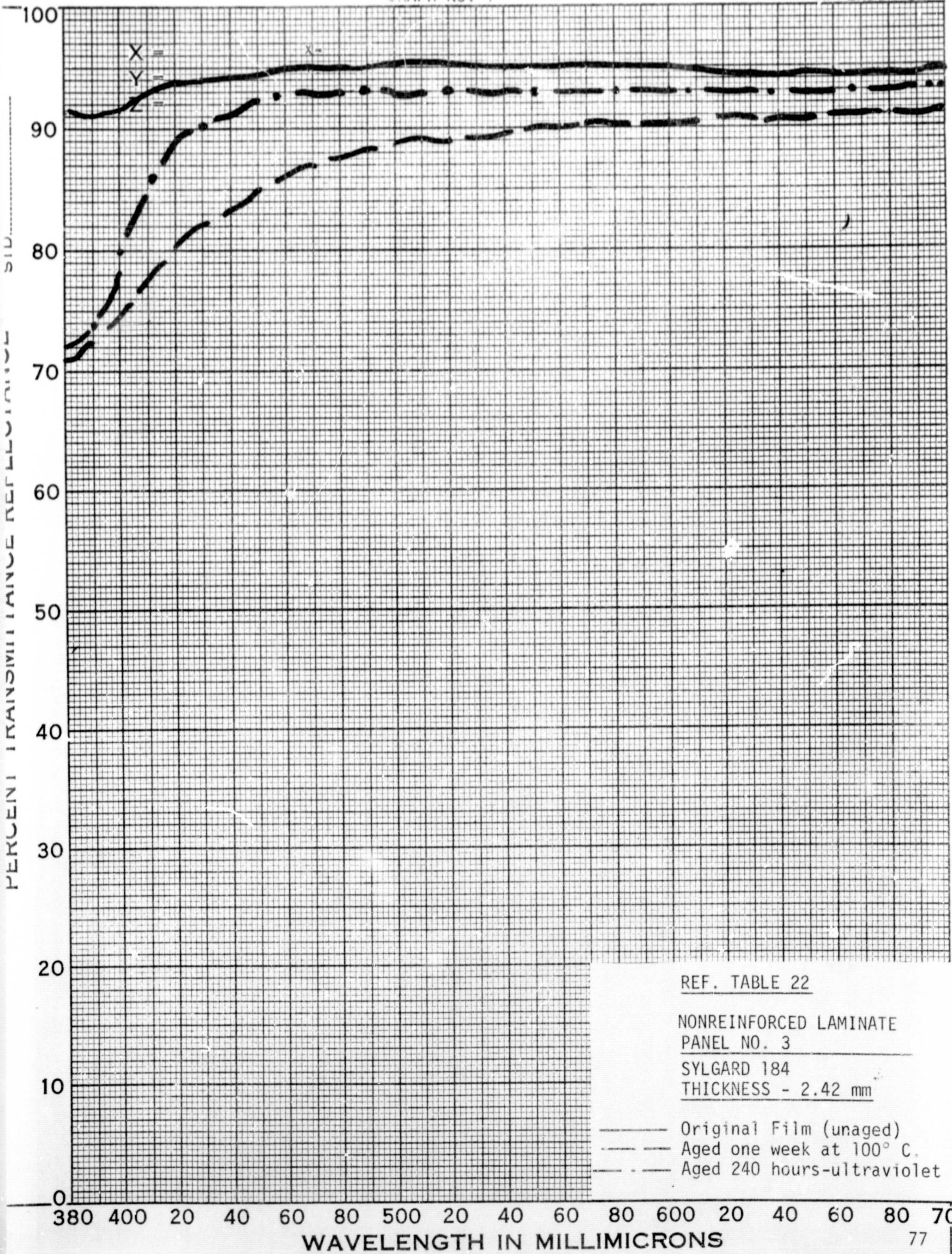
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 2
CONATHANE EN1554
THICKNESS - 2.71 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet

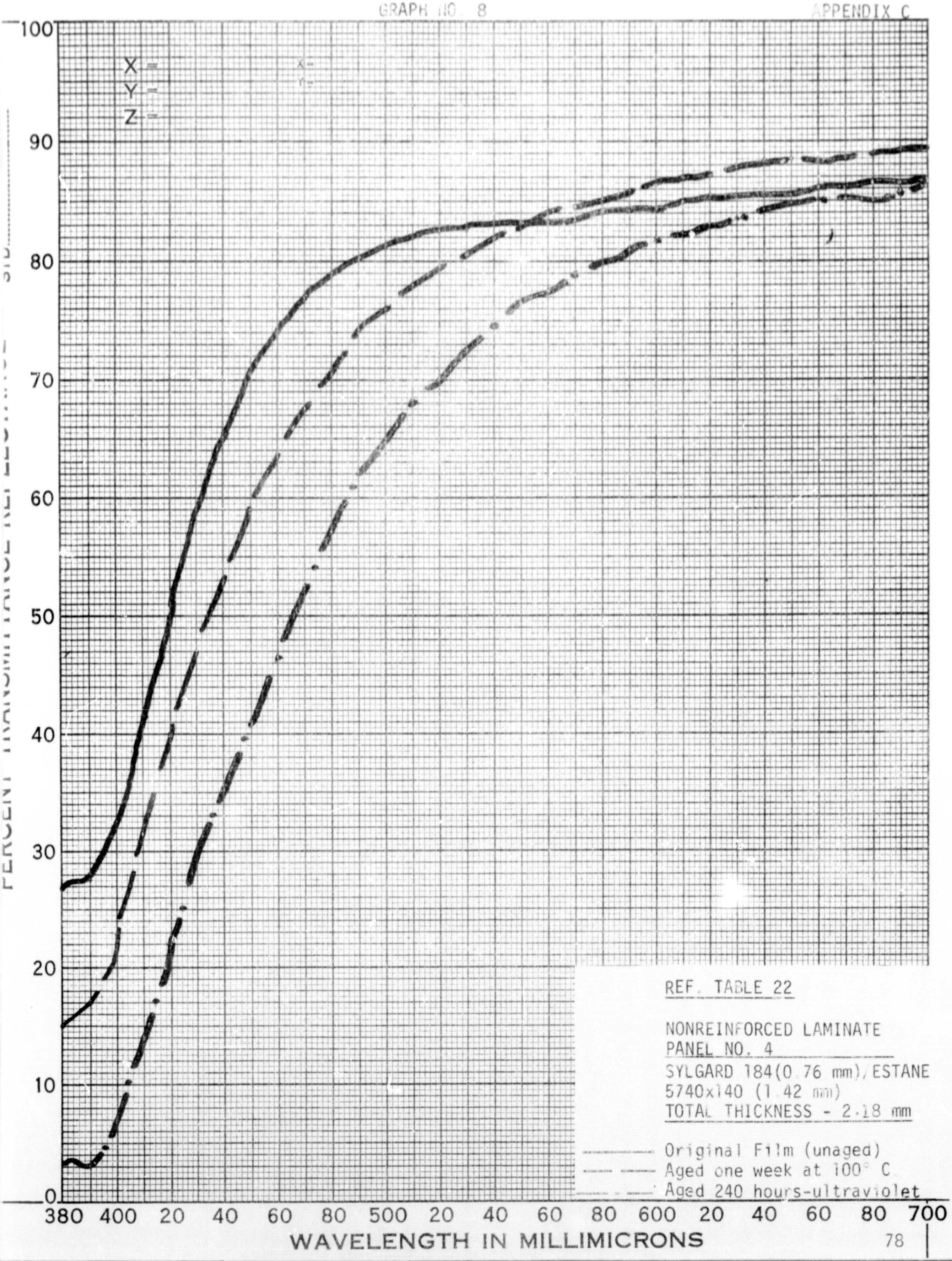


REF. TABLE 22

NONREINFORCED LAMINATE
PANEL NO. 3

SYLGARD 184
THICKNESS - 2.42 mm

——— Original Film (unaged)
— — Aged one week at 100° C.
— · — Aged 240 hours-ultraviolet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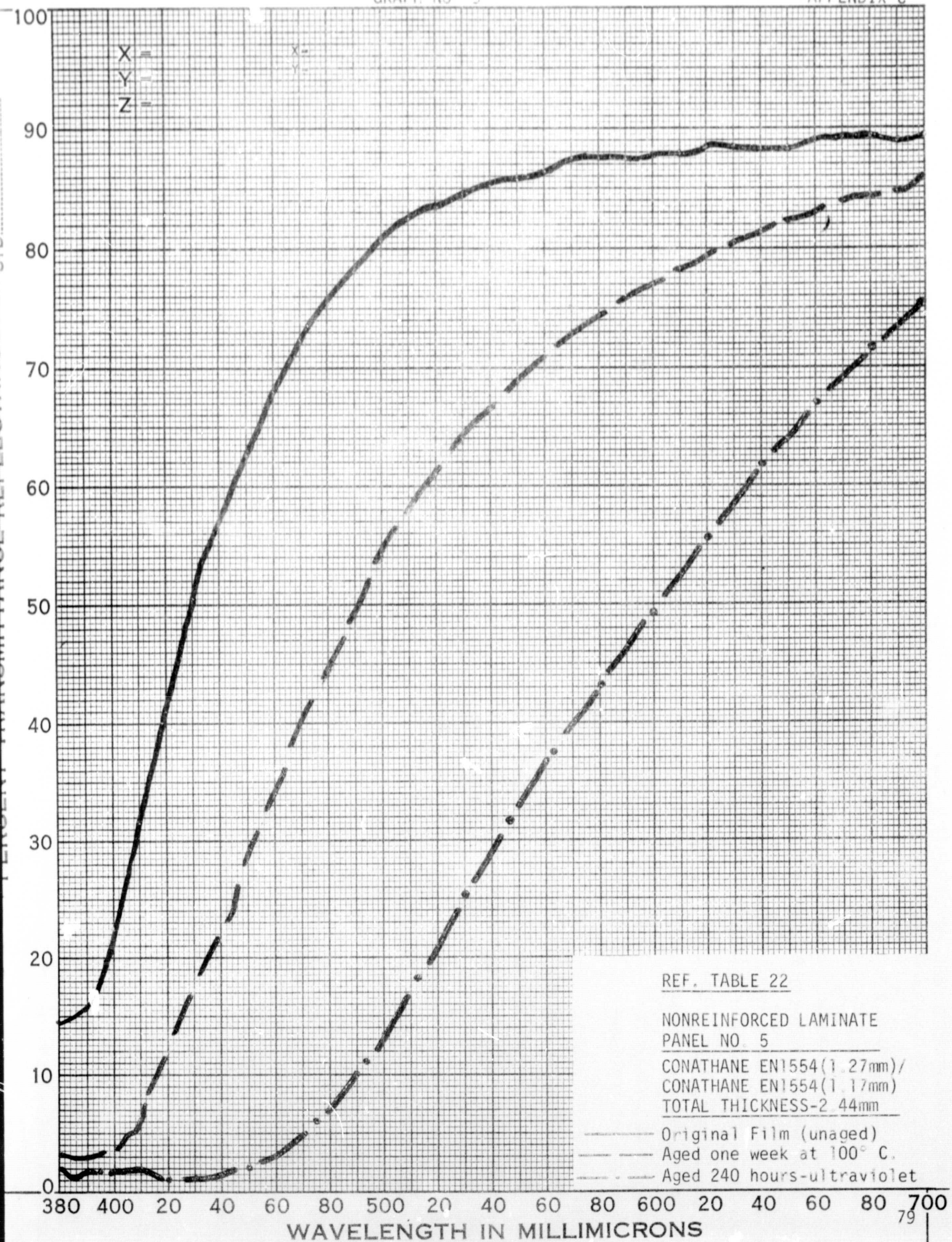
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 4
SYLGARD 184(0.76 mm)/ESTANE
5740x140 (1.42 mm)
TOTAL THICKNESS - 2.18 mm
Original Film (unaged)
Aged one week at 100° C
Aged 240 hours-ultraviolet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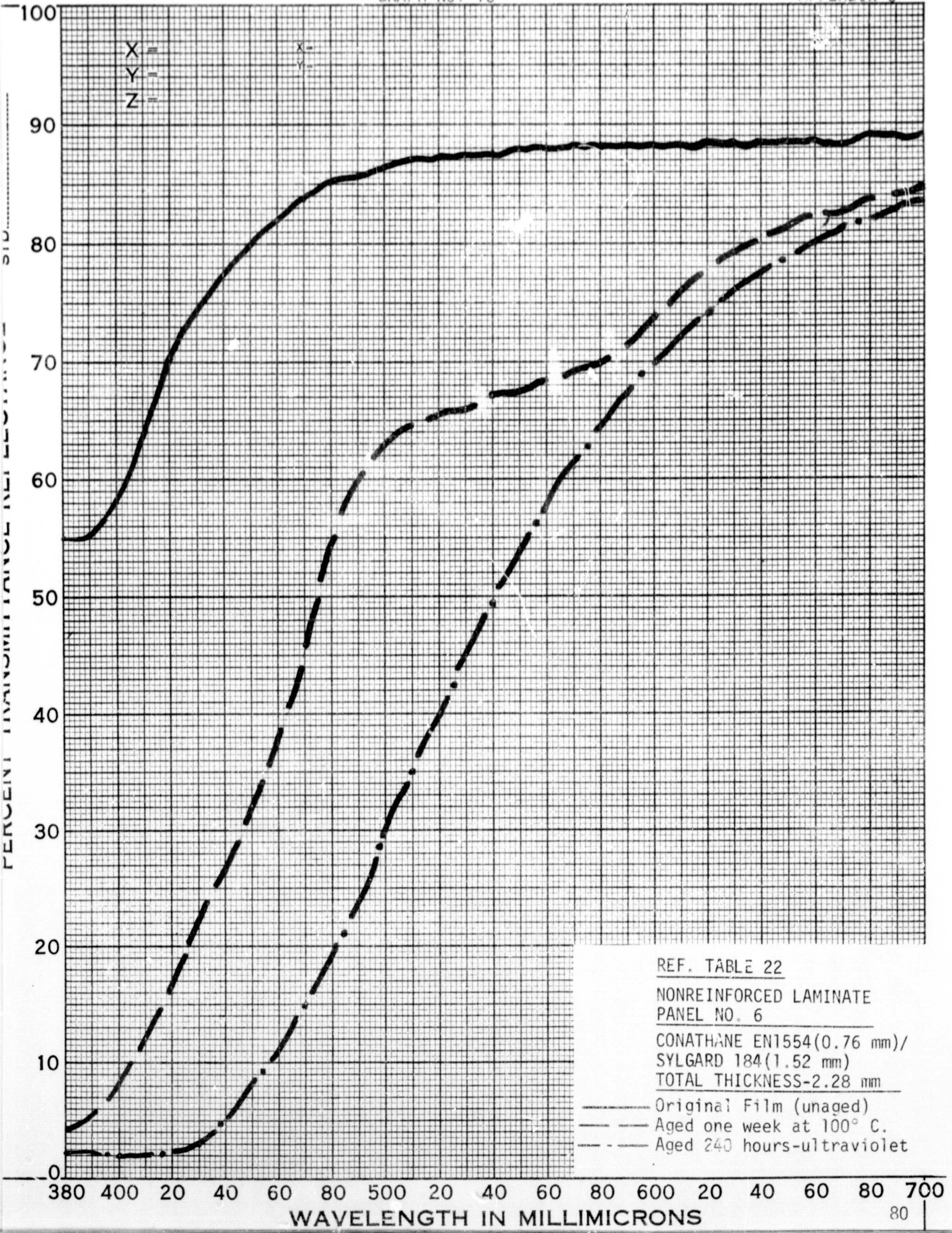
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 5
CONATHANE EN1554(1.27mm)/
CONATHANE EN1554(1.17mm)
TOTAL THICKNESS-2.44mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet


PERCENT TRANSMITTANCE REFLECTANCE
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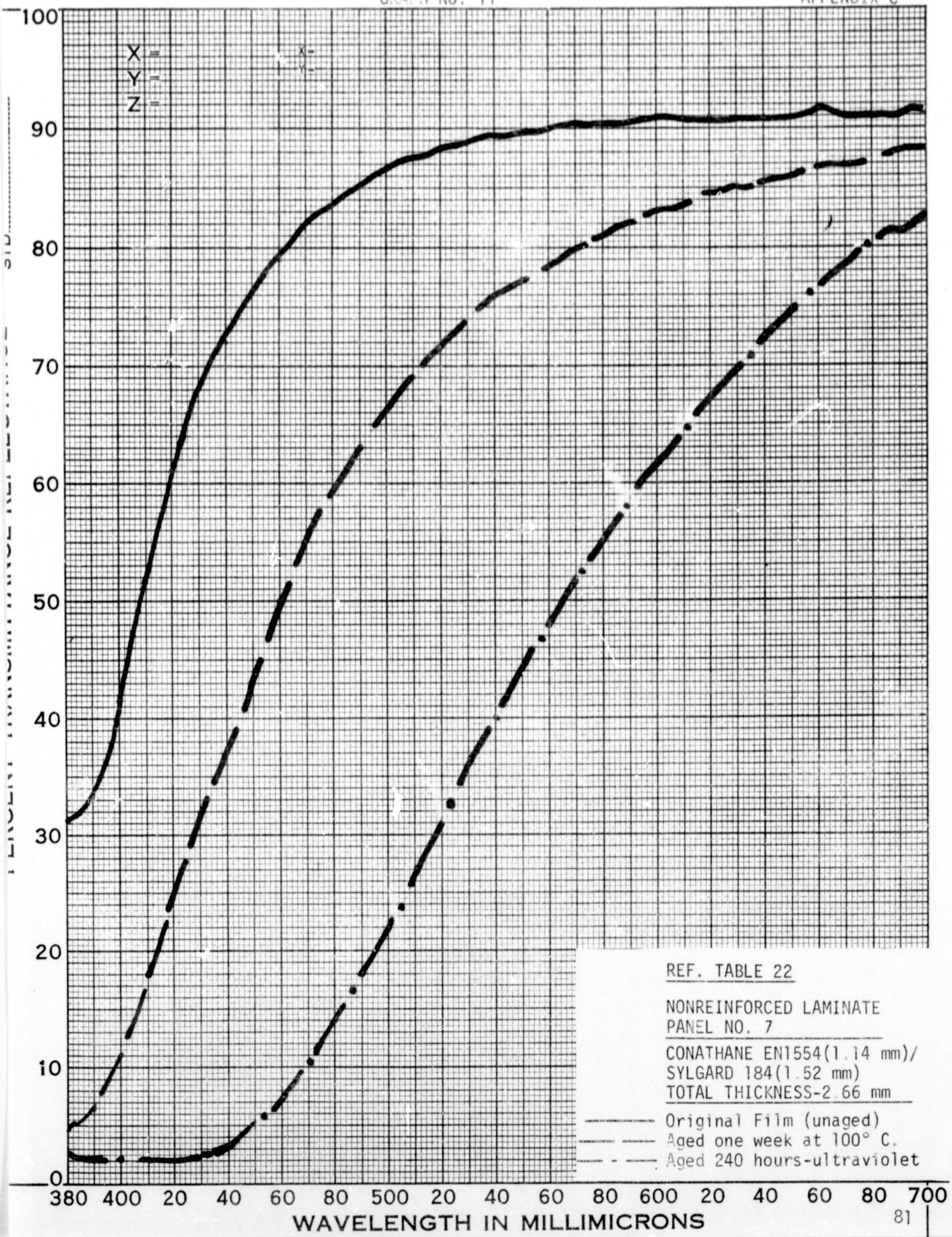
X =
Y =
Z =
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 6
CONATHANE EN1554(0.76 mm)/
SYLGARD 184(1.52 mm)
TOTAL THICKNESS-2.28 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet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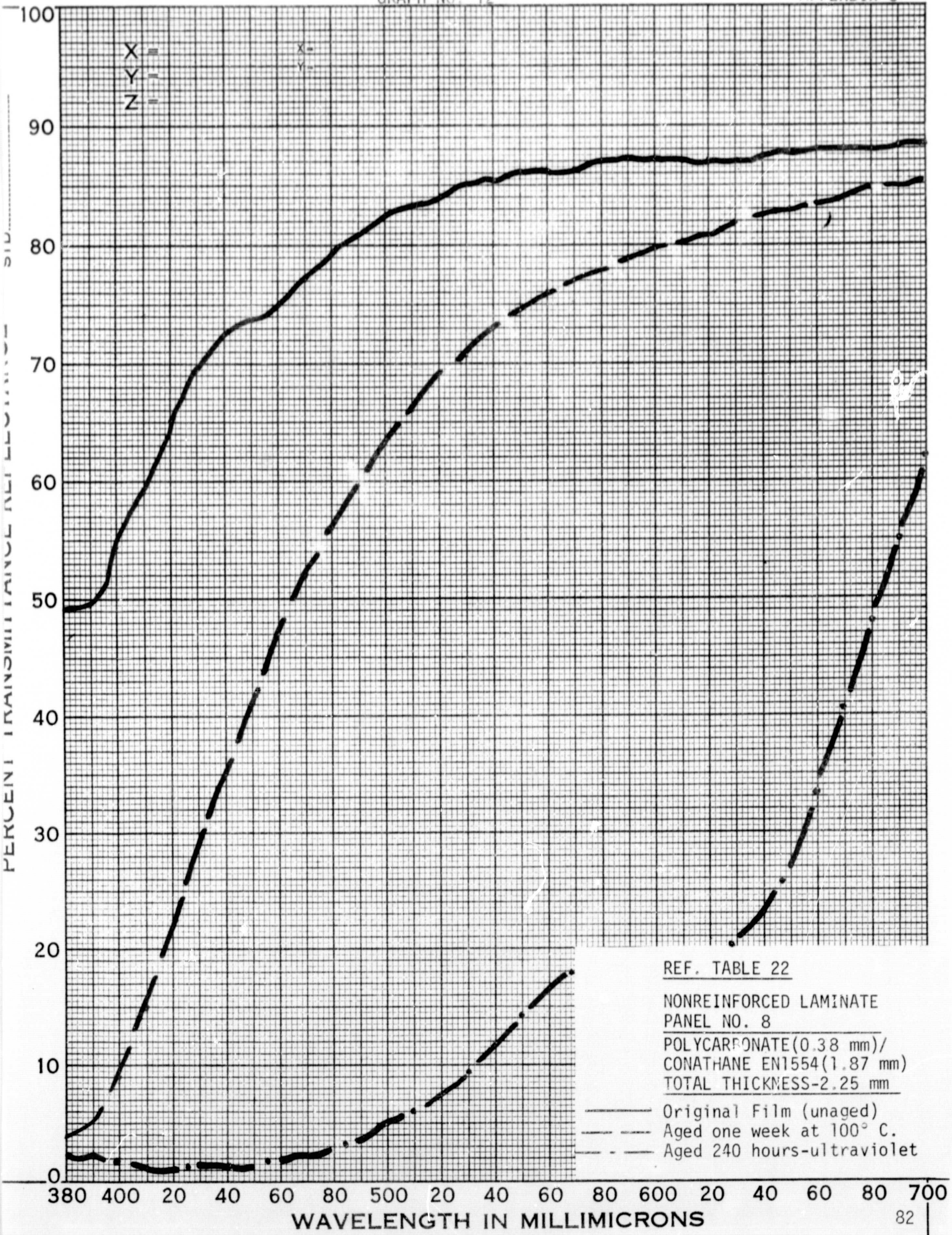
Y-
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 7
CONATHANE EN1554(1.14 mm)/
SYLGARD 184(1.52 mm)
TOTAL THICKNESS-2.66 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet

GRAPH NO. 12


X =
Y =
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PERCENT TRANSMITTANCE REFLECTANCE
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380
400
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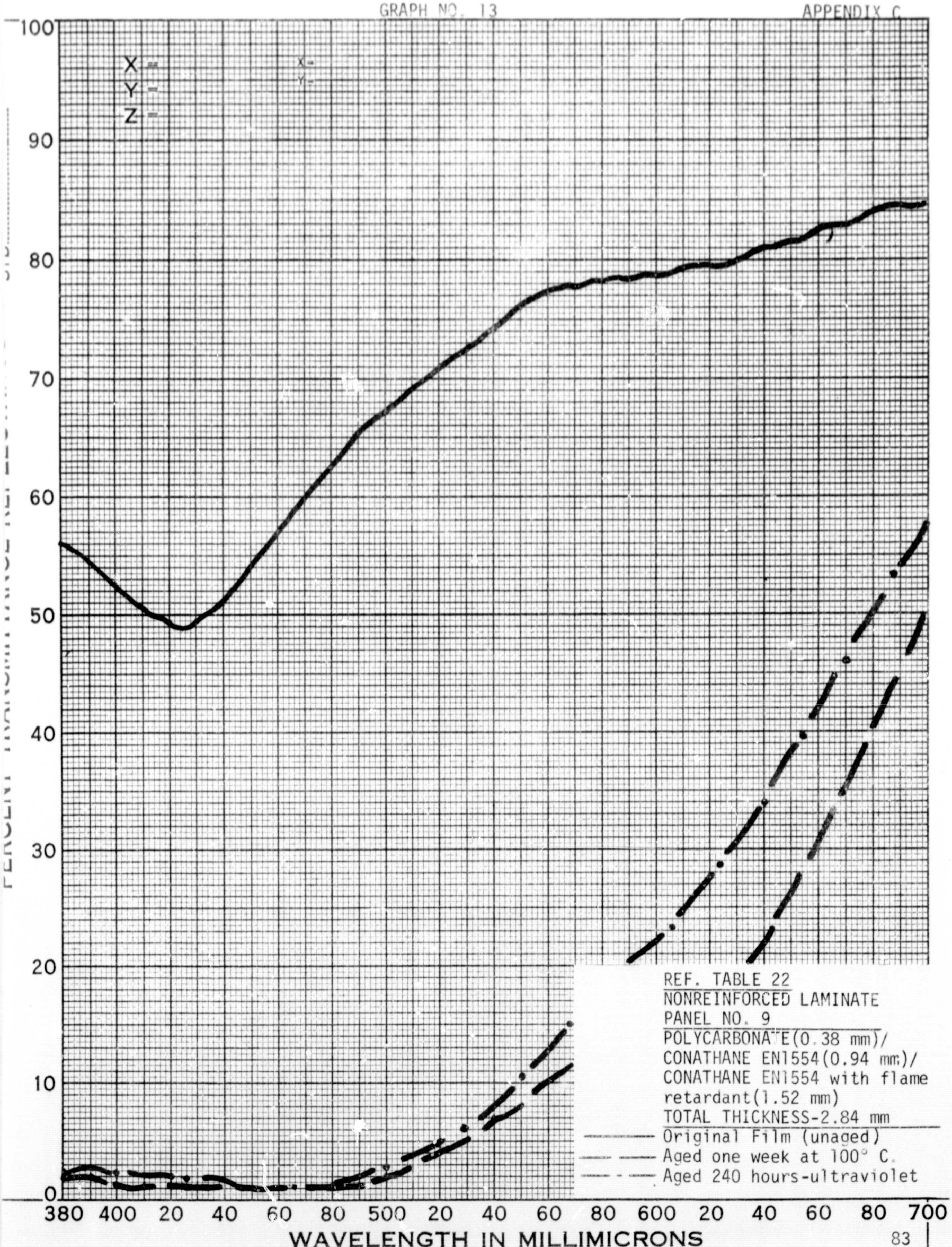
80
500
20
40
60
80
600
20
40
60
80
700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 8
POLYCARBONATE(0.38 mm)/
CONATHANE EN1554(1.87 mm)
TOTAL THICKNESS-2.25 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet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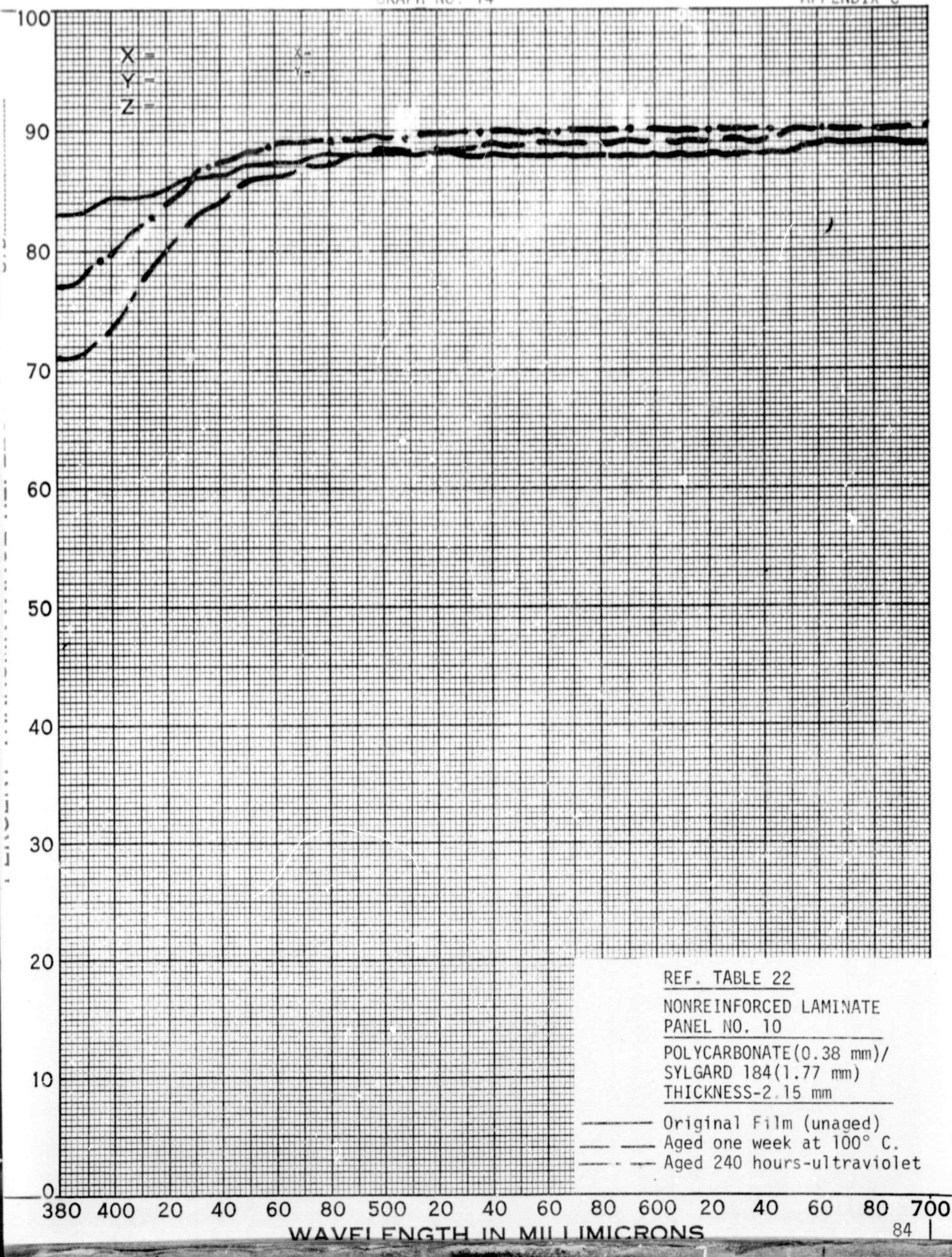
PERCENT TRANSMITTANCE REFLECTANCE
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 9
POLYCARBONATE(0.38 mm)/
CONATHANE EN1554(0.94 mm)/
CONATHANE EN1554 with flame retardant(1.52 mm)
TOTAL THICKNESS-2.84 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet



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X =
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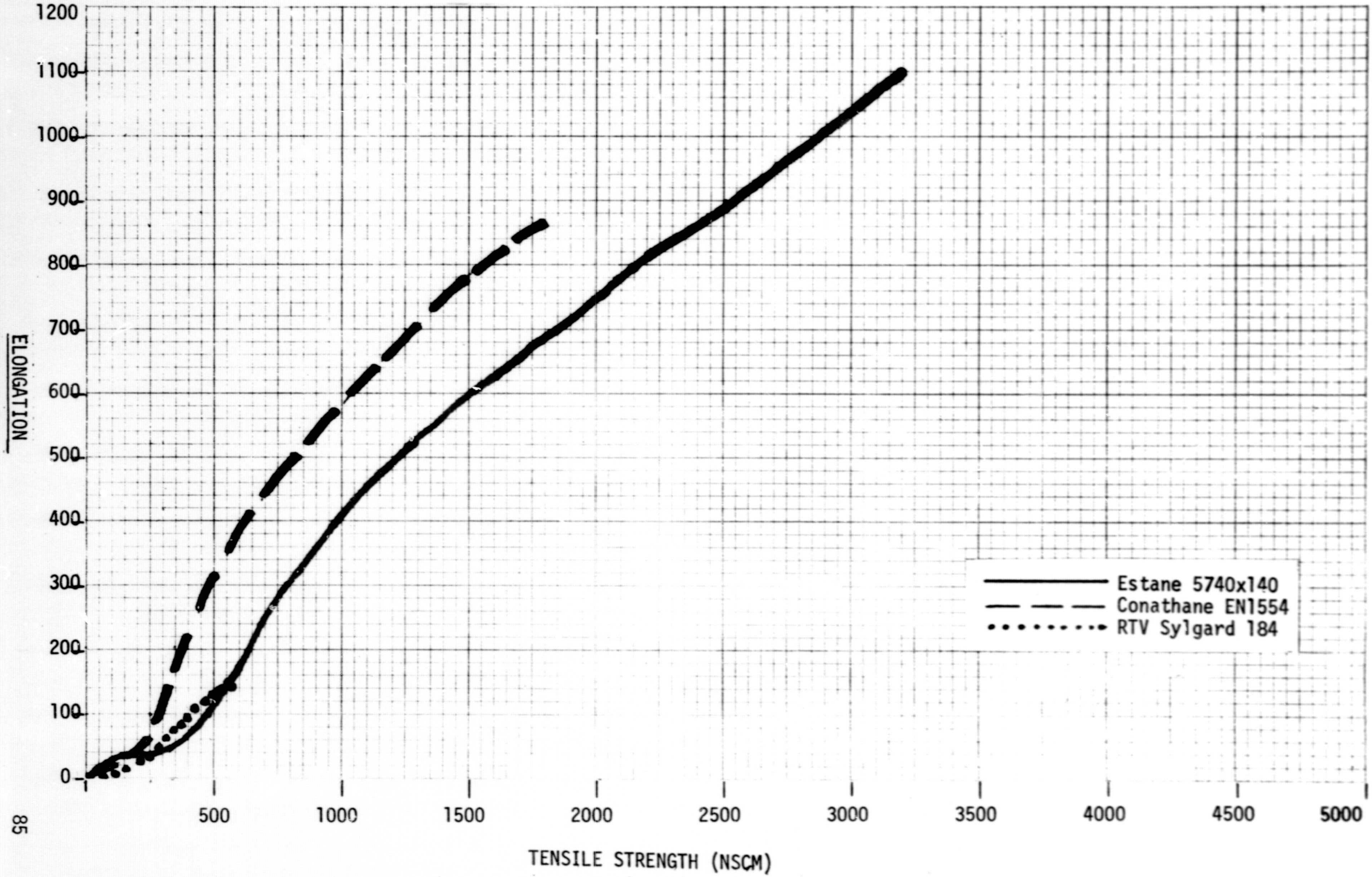
Z =
380 400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700
WAVELENGTH IN MILLIMICRONS
REF. TABLE 22
NONREINFORCED LAMINATE
PANEL NO. 10
POLYCARBONATE(0.38 mm)/
SYLGARD 184(1.77 mm)
THICKNESS-2.15 mm
Original Film (unaged)
Aged one week at 100° C.
Aged 240 hours-ultraviolet

GRAPH NO. 15 REF. TABLE 17



ABSTRACT

The objective of the work conducted on NASA Contract NASI-7771 was to develop an improved, flexible, transparent space window suitable for use in a flexible expandable space structure.

Seventeen polymers selected from three generically different types were evaluated as the potential matrix materials in the composite.

Two glass rovings and two steel filaments were evaluated as reinforcement media.

Polyether urethane was the matrix material selected for continued evaluation in combination with a glass roving or steel filament reinforcement.

Four basic reinforcement patterns were evaluated during the course of the contract. An adhesive means of installing resultant windows in simulated space structure panels were evaluated. Simulated space structure panels with windows installed, utilizing adhesive methods were tested under a sustained pressure of 4.86 nscm for 24 hours followed by pressurization to burst.

Filament-wound cylindrical chambers with hemispherical ends and incorporating a flexible transparent window of polyether urethane matrix with brass plated, steel, rocket wire cable reinforcement encapsulated in a barrier film of dimethyl silicone in the cylindrical section were hydroproofed at 14.58 nscm.